PERFORMANCE ANALYSIS OF ACTIVATED SLUDGE PROCESS AND ENHANCEMENT OF ENERGY YIELD USING EXCESS SLUDGE AS A FLOCCULENT IN THE PRIMARY SETTLING TANK - A CASE STUDY OF STP DELAWAS

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Ph.D. thesis on

Performance analysis of activated sludge process and enhancement of energy yield using excess sludge as a flocculent in the primary settling tank - A case study of STP Delawas

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Declaration

I declare that the work which is being presented in the Ph. D. Thesis entitled **Performance analysis of activated sludge process and enhancement of energy yield using excess sludge as a flocculent in the primary settling tank - A case study of STP Delawas** in partial fulfillment of the requirement for the award of the degree of Ph.D. in Civil Engineering submitted to the Department of Civil Engineering, Malaviya National Institute of Technology Jaipur is an authentic record of my own work carried out from July, 2007 to August, 2015 under the supervision and guidance of Dr. A.B. Gupta, Professor, Department of Civil Engineering, MNIT Jaipur and Dr. R.K. Vyas, Associate Professor, Department of Chemical Engineering MNIT Jaipur. Information used from literature and other sources in the present thesis has been duly acknowledged by citing references at appropriate places. In case any type of plagiarism found, I will be solely and completely responsible for it. I have checked plagiarism through plagiarism software (Turnitin.Com). The chart showed 14% plagiarism in the whole thesis.

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Dharmraj Jangid

ABSTRACT

A case study for the performance analysis of conventional Activated Sludge Process (ASP) of Sewage Treatment Plant (STP) Delawas, Jaipur and use of excess sludge as a flocculent in the Primary Settling Tank (PST) was carried out to enhance the operational efficiency of secondary treatment unit and improve the settling characteristics in PST. The performance was assessed through a critical analysis of the existing records in order to bring out certain issues resulting in low efficiency. Primary experiments were carried out at the STP site by adding different types of sludges in raw sewage at PST (in different sets) to come out with an efficient solution. The assessment of energy consumed by different units of the STP showed that energy consumed for aeration was lower than the designed value, primarily due to low dissolved oxygen (DO) levels being maintained in the aeration tank. This was reflected in the lower power consumption by about 20% than the designed guaranteed power requirement of STP. As a consequence, microbiological quality of the treated effluent suffered adversely, affecting the environment and possibly, a significant increase in the cost of tertiary treatment including disinfection in future.

A unique methodology was developed during this study for gaining insight into the performance of the STP using routine records of organics removal and the apportionment of power consumption to individual units. The performance kinetics for oxidation in aeration tank showed that the performance in terms of biochemical oxygen demand (BOD) removal was satisfactory despite lower hydraulic retention time (HRT) of 4 h being maintained than the designed value of 6 h. This was due to the fact that solid retention time (SRT, θ_c) varied in the range of 6.66 to 12.95 days against the designed value of 8 days. Lower SRT resulted in impaired performance leading to poor settleability and low secondary sludge biomass concentration. The PST performance data showed that BOD_5 removal was about 40% indicating scope for improvement. This approach can help develop protocols for continuous assessment and diagnostics for troubleshooting at STPs and optimize the process both in terms of organics removal as well as energy demand.

A comprehensive study was designed to improve the performance of PST through controlled mixing of excess secondary sludge in different proportions to raw sewage entering to PST to enhance settling of colloidal particles of raw sewage.

Digested sludge from anaerobic and aerobic sludge digesters of STP Delawas (Jaipur South) and STP Brahmapuri (Jaipur North) respectively were tried for this purpose, with the latter giving excellent results. Encouraged by these results, part of the thickened secondary excess sludge from STP Delawas was then aerobically digested and the process was repeated with the municipal sewage entering STP Delawas indicating higher benefits of sludge conditioning in improvement of PST efficiency. Use of secondary return sludge @ 30 mL/L of sewage as a flocculent in the PST resulted in improvement in total suspended solids (TSS) and BOD_5 and filtered BOD_5 removal compared to the existing system, where this return sludge was going to the aeration tank directly. The results for similar experiments with anaerobically digested sludge did not yield encouraging results and thickened sludge from STP Delawas showed a marginal benefit over return sludge. Use of return sludge from STP Brahmapuri, functioning on extended aeration process with aerobic sludge digestion showed some improvement in the system (Repeated). Addition of the thickened sludge from the STP Delawas in volumetric concentrations of 1% to 5% after a brief aeration of 20 min was tried; 1% volume used as a flocculent removed 3% and 5% higher TSS and BOD_5 as compared to the existing system.

This resulted in extra energy savings of about 15% through extra generation of energy using primary sludge and reduction in aeration demand. This may have been caused by migration of dissolved organics in to the microbial akin to a contact tank of contact-stabilization process. The results of these experiments can be used with high benefits in optimizing energy use in STPs wherever energy generation is carried out from waste sludges.

TABLE OF CONTENTS

	Candidate's Declaration	
	Acknowledgement	i
	Abstract	iii
	Table of Contents	v
	List of Tables	vii
	List of Figures	ix
	List of Abbreviations	xiii
	List of Notations	xv
	List of Publications	
1.	INTRODUCTION	1
1.1	Wastewater Treatment Options	1
1.2	Activated Sludge Process	2
1.3	Study Area	4
1.4	Objective of Thesis Work	9
1.5	Structure of The Thesis	10
2.	LITERATURE REVIEW	11
2.1	Municipal wastewater	11
2.2	General impurities in municipal wastewater	12
2.3	Typical treated effluent standards	13
2.4	Classification of common wastewater treatment processes	16
2.5	Land requirement and capital cost for STPs	18
2.6	Power and O&M costs	19
2.7	Process selection	20
2.8	Activated sludge process	22
2.9	Sludge handling	23
2.10	Worldwide power generation through biogas	24
2.11	Performance enhancement of PSTs	33
3.	BIOLOGICAL PERFORMANCE ANALYSIS OF STP	35
3.1.	Salient features of STP Delawas unit-I	35
3.2.	Description of the STP	37
3.3.	Influent and effluent parameters	39
3.4.	Performance of aeration tank	43
3.5.	Operation and Maintenance Cost	49
3.6.	Power consumption in operation of STP	51
3.7.	Unit wise power consumption	53

3.8. Power drawn from grid 56
3.9. Power generation unit of STP 58
3.10. Primary settling tank performance 66
3.11. Contribution of the study presented in this chapter 68
4. PERFORMANCE ENHANCEMENT OF PST BY ADDITION OF BIOLOGICAL SLUDGES AS FLOCCULENT - EXPERIMENTAL STUDY 71
4.1. Experimental set up and methodology for laboratory experiments 72
4.2. Results and discussion 76
4.2.1. Experiments with addition of secondary excess sludge from STP Delawas 76
4.2.1.1. Settling characteristics of raw sewage 76
4.2.1.2. Characteristics of excess sludge used for the settling experiments 77
4.2.2. Settling experiments with thickened sludge from STP Delawas 91
4.2.3. Settling experiments with anaerobically digested sludge from STP Delawas 102
4.2.4. Experiments with addition of secondary excess sludge from STP Brahmapuri 114
4.2.5. Settling experiments with aerobically digested sludge from STP Brahmapuri 126
4.2.6. Settling experiments with briefly aerated thickened return sludge from STP Delawas 138
4.3. Particle size analysis of suspensions in the PST after flocculation and settling induced by different sludges 152
4.4. Suggestive Theoretical Energy Calculations after modification 157
4.5. Study outcome and contribution 161
4.6. Suggestions to the Operator from this study 164
5. CONCLUSION, CONTRIBUTION AND RECOMMENDATION FOR FUTURE WORK 167
5.1. Conclusion 167
5.2. Scope for future research 171

REFERENCES 173
APPENDIX 1 - PARTICLE SIZE DISTRIBUTION - MASTERSIZER-2000 181
APPENDIX 2 - LAYOUT, HYDRAULICS FLOW DRAWING AND PHOTOGRAPHS OF PLANT STUDIED 193
APPENDIX 3 – OBSERVED AND CALCULATED VALUES WITH ADDITION OF VARIOUS SLUDGE IN VARIOUS VOLUME 197
LIST OF PAPERS PUBLISHED IN NATIONAL/INTERNATIONAL JOURNALS 203

LIST OF TABLES

Table 2.1	Contaminants, their significance and origin of wastewater (Metcalf and Eddy Inc, 1991)	12
Table 2.2	General Standards for discharge of environmental pollutants (Environment Protection Rules 1980 CPCB, Government of India)	13
Table 2.3	Classification of common treatment processes (Arceivala, 2003)	16
Table 2.4	Expected efficiency of various treatment units (Arceivala, 2003)	16
Table 2.5	Land requirement and capital cost for STPs	18
Table 2.6	Power consumption and O&M costs for 5 - 10 MLD Sewage treatment plants (UDH, Raj. 2011)	19
Table 2.7	Selection of treatment process and required treated wastewater parameters	21
Table 2.8	World power generation at a glance during the year 2009 (Jaiswal, K M., MNIT, Jaipur 2012)	26
Table 2.9	Summary of published literature on wastewater treatment	27
Table 3.1	Design influent parameters and effluent parameters of STP Delawas (Requirements of STP Delawas RUIDP, Jaipur, 2003)	38
Table 3.2	Monthly average characteristics of raw and treated sewage and their standard deviation	40
Table 3.3	Measured characteristics of sewage showing color at the inlet of STP	42
Table 3.4	Derived monthly average values for influent and effluent of secondary level process	44
Table 3.5	Estimation of specific solids growth rate and Sludge age (θc) values of aerobic oxidation at STP Delawas Jaipur	47
Table 3.6	Operation and Maintenance Cost of STP (M/s VA TECH WABAG., Jaipur STP Delawas, 2013)	50
Table 3.7	Summary of monthly power consumed at Delawas STP derived from plant operation data (M/s Va Tech Wabag Jaipur, 2013)	51
Table 3.8	Unit wise power consumption derived on the basis of operating installed load (Documents of M/s Vatech Wabag, 2013)	53
Table 3.9	Unit wise calculated (required) power	55
Table 3.10	Power drawn from grid after installation of power generation unit	56
Table 3.11	Characteristics of biogas produced during sludge digestion (M/s Va tech Wabag, 2013)	59
Table 3.12	Cost viability calculations for power generation unit	60
Table 3.13	Details of bio gas generated from the digester	61
Table 3.14	Monthly power generated from biogas	61
Table 3.15	Power consumption before and after installation of power generation unit	64
Table 3.16	Primary Clarifier inlet & outlet parameters	67
Table 4.1	Results of settling of raw sewage sample I	77
Table 4.2	Characteristics of excess sludge of STP Delawas	78
Table 4.3	Results of settling of raw sewage sample II	78

Table 4.4	Characteristic of aerobically digested sludge of 27 MLD STP Brahampuri (extended aeration process)	127
Table 4.5	Results of settling of raw sewage sample VI	139
Table 4.6	Properties of briefly aerated thickened sludge of STP, Delawas	139
Table 4.7	Volume fraction and particle size distribution of raw sewage with and without addition of sludges in various volumes	154
Table 4.8	Power saving calculations for STP operation after performance improvement of PST	157

LIST OF FIGURES

Figure 3.1 Overview of STP 36
Figure 3.2 Overview of power generation unit with gas holders 36
Figure 3.3 Overview of Digester units 59
Figure 3.4 Biogas based power generation unit of STP Delawas Jaipur 63
Figure 3.5 Gas holder and power generator room of STP Delawas Jaipur 64
Figure 4.1 Experimental set up (Imhoff Cone) 73
Figure 4.2 Modified scheme of PST 75
Figure 4.3 Existing scheme of PST 75
Figure 4.4 TSS removal with 10 mL return sludge 79
Figure 4.5 COD removal with 10 mL return sludge 80
Figure 4.6 BOD removal with 10 mL return sludge 80
Figure 4.7 fBOD removal with 10 mL return sludge 80
Figure 4.8 TSS removal with 20 mL return sludge 82
Figure 4.9 COD removal with 20 mL return sludge 82
Figure 4.10 BOD removal with 20 mL return sludge 83
Figure 4.11 fBOD removal with 20 mL return sludge 83
Figure 4.12 TSS removal with 30 mL return sludge 84
Figure 4.13 COD removal with 30 mL return sludge 84
Figure 4.14 BOD removal with 30 mL return sludge 85
Figure 4.15 fBOD removal with 30 mL return sludge 85
Figure 4.16 TSS removal with 40 mL return sludge 86
Figure 4.17 COD removal with 40 mL return sludge 86
Figure 4.18 BOD removal with 40 mL return sludge 87
Figure 4.19 fBOD removal with 40 mL return sludge 87
Figure 4.20 TSS removal with 50 mL return sludge 88
Figure 4.21 COD removal with 50 mL return sludge 88
Figure 4.22 BOD removal with 50 mL return sludge 89
Figure 4.23 fBOD removal with 50 mL return sludge 89
Figure 4.24 TSS removal with 10 mL thickened sludge 92
Figure 4.25 COD removal with 10 mL thickened sludge 92
Figure 4.26 BOD removal with 10 mL thickened sludge 93
Figure 4.27 fBOD removal with 10 mL thickened sludge 93
Figure 4.28 TSS removal with 20 mL thickened sludge 94
Figure 4.29 COD removal with 20 mL thickened sludge 94
Figure 4.30 BOD removal with 20 mL thickened sludge 95

Figure 4.31 fBOD removal with 20 mL thickened sludge 95
Figure 4.32 TSS removal with 30 mL thickened sludge 96
Figure 4.33 COD removal with 30 mL thickened sludge 96
Figure 4.34 BOD removal with 30 mL thickened sludge 97
Figure 4.35 fBOD removal with 30 mL thickened sludge 97
Figure 4.36 TSS removal with 40 mL thickened sludge 98
Figure 4.37 COD removal with 40 mL thickened sludge 98
Figure 4.38 BOD removal with 40 mL thickened sludge 99
Figure 4.39 fBOD removal with 40 mL thickened sludge 99
Figure 4.40 TSS removal with 50 mL thickened sludge 100
Figure 4.41 COD removal with 50 mL thickened sludge 100
Figure 4.42 BOD removal with 50 mL thickened sludge 101
Figure 4.43 fBOD removal with 50 mL thickened sludge 101
Figure 4.44 TSS removal with 10 mL anaerobically digested sludge 104
Figure 4.45 COD removal with 10 mL anaerobically digested sludge 104
Figure 4.46 BOD removal with 10 mL anaerobically digested sludge 105
Figure 4.47 fBOD removal with 10 mL anaerobically digested sludge 105
Figure 4.48 TSS removal with 20 mL anaerobically digested sludge 106
Figure 4.49 COD removal with 20 mL anaerobically digested sludge 106
Figure 4.50 BOD removal with 20 mL anaerobically digested sludge 107
Figure 4.51 fBOD removal with 20 mL anaerobically digested sludge 107
Figure 4.52 TSS removal with 30 mL anaerobically digested sludge 108
Figure 4.53 COD removal with 30 mL anaerobically digested sludge 108
Figure 4.54 BOD removal with 30 mL anaerobically digested sludge 109
Figure 4.55 fBOD removal with 30 mL anaerobically digested sludge 109
Figure 4.56 TSS removal with 40 mL anaerobically digested sludge 110
Figure 4.57 COD removal with 40 mL anaerobically digested sludge 110
Figure 4.58 BOD removal with 40 mL anaerobically digested sludge 111
Figure 4.59 fBOD removal with 40 mL anaerobically digested sludge 111
Figure 4.60 TSS removal with 50 mL anaerobically digested sludge 112
Figure 4.61 COD removal with 50 mL anaerobically digested sludge 112
Figure 4.62 BOD removal with 50 mL anaerobically digested sludge 113
Figure 4.63 fBOD removal with 50 mL anaerobically digested sludge 113
Figure 4.64 TSS removal with 10 mL return sludge (extended aeration) 116
Figure 4.65 COD removal with 10 mL return sludge (extended aeration) 116
Figure 4.66 BOD removal with 10 mL return sludge (extended aeration) 117
Figure 4.67 fBOD removal with 10 mL return sludge (extended aeration) 117

Figure 4.68 TSS removal with 20 mL return sludge (extended aeration) 118
Figure 4.69 COD removal with 20 mL return sludge (extended aeration) 118
Figure 4.70 BOD removal with 20 mL return sludge (extended aeration) 119
Figure 4.71 fBOD removal with 20 mL return sludge (extended aeration) 119
Figure 4.72 TSS removal with 30 mL return sludge (extended aeration) 120
Figure 4.73 COD removal with 30 mL return sludge (extended aeration) 120
Figure 4.74 BOD removal with 30 mL return sludge (extended aeration) 121
Figure 4.75 fBOD removal with 30 mL return sludge (extended aeration) 121
Figure 4.76 TSS removal with 40 mL return sludge (extended aeration) 122
Figure 4.77 COD removal with 40 mL return sludge (extended aeration) 122
Figure 4.78 BOD removal with 40 mL return sludge (extended aeration) 123
Figure 4.79 fBOD removal with 40 mL return sludge (extended aeration) 123
Figure 4.80 TSS removal with 50 mL return sludge (extended aeration) 124
Figure 4.81 COD removal with 50 mL return sludge (extended aeration) 124
Figure 4.82 BOD removal with 50 mL return sludge (extended aeration) 125
Figure 4.83 fBOD removal with 50 mL return sludge (extended aeration) 125
Figure 4.84 TSS removal with 10 mL aerobically digested sludge 128
Figure 4.85 COD removal with 10 mL aerobically digested sludge 128
Figure 4.86 BOD removal with 10 mL aerobically digested sludge 129
Figure 4.87 fBOD removal with 10 mL aerobically digested sludge 129
Figure 4.88 TSS removal with 20 mL aerobically digested sludge 130
Figure 4.89 COD removal with 20 mL aerobically digested sludge 130
Figure 4.90 BOD removal with 20 mL aerobically digested sludge 131
Figure 4.91 fBOD removal with 20 mL aerobically digested sludge 131
Figure 4.92 TSS removal with 30 mL aerobically digested sludge 132
Figure 4.93 COD removal with 30 mL aerobically digested sludge 132
Figure 4.94 BOD removal with 30 mL aerobically digested sludge 133
Figure 4.95 fBOD removal with 30 mL aerobically digested sludge 133
Figure 4.96 TSS removal with 40 mL aerobically digested sludge 134
Figure 4.97 COD removal with 40 mL aerobically digested sludge 134
Figure 4.98 BOD removal with 40 mL aerobically digested sludge 135
Figure 4.99 fBOD removal with 40 mL aerobically digested sludge 135
Figure 4.100 TSS removal with 50 mL aerobically digested sludge 136
Figure 4.101 COD removal with 50 mL aerobically digested sludge 136
Figure 4.102 BOD removal with 50 mL aerobically digested sludge 137
Figure 4.103 fBOD removal with 50 mL aerobically digested sludge 137
Figure 4.104 TSS removal with 10 mL briefly aerated thickened sludge 140

Figure 4.105 COD removal with 10 mL briefly aerated thickened sludge 140
Figure 4.106 BOD removal with 10 mL briefly aerated thickened sludge 141
Figure 4.107 fBOD removal with 10 mL briefly aerated thickened sludge 141
Figure 4.108 TSS removal with 20 mL briefly aerated thickened sludge 1412
Figure 4.109 COD removal with 20 mL briefly aerated thickened sludge 142
Figure 4.110 BOD removal with 20 mL briefly aerated thickened sludge 143
Figure 4.111 fBOD removal with 20 mL briefly aerated thickened sludge 143
Figure 4.112 TSS removal with 30 mL briefly aerated thickened sludge 144
Figure 4.113 COD removal with 30 mL briefly aerated thickened sludge 144
Figure 4.114 BOD removal with 30 mL briefly aerated thickened sludge 145
Figure 4.115 fBOD removal with 30 mL briefly aerated thickened sludge 145
Figure 4.116 TSS removal with 40 mL briefly aerated thickened sludge 146
Figure 4.117 COD removal with 40 mL briefly aerated thickened sludge 146
Figure 4.118 BOD removal with 40 mL briefly aerated thickened sludge 147
Figure 4.119 fBOD removal with 40 mL brief aerated thickened sludge 147
Figure 4.120 TSS removal with 50 mL briefly aerated thickened sludge 148
Figure 4.121 COD removal with 50 mL brief aerated thickened sludge 148
Figure 4.122 BOD removal with 50 mL briefly aerated thickened sludge 149
Figure 4.123 fBOD removal with 50 mL briefly aerated thickened sludge 149
Figure 4.124 Experiment set up for Jar test 152
Figure 4.125 Recommended /Modified flow diagram of 62.50 MLD STP unit-I, Delawas Jaipur 166

LIST OF ABBREVIATION

ASP	Activated sludge process
AT	Aeration Tank
BOD_5	Biochemical oxygen demand for 5days at 20°C
C.C.R.C.P	Chennai City River Conservation Project
CETPs	Common effluent treatment plants
COD	Chemical oxygen demand
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organization
EPA, CPPD	Environment Protection Agency, Climate Protection Partnerships Division (CPPD)
$fBOD_5$	Filtered biochemical oxygen demand for 5days at 20°C
GWhE	Giga Watt hour Electricity
HFL	High Flood Level
HRT	Hydraulic Retention Time
JMC	Jaipur Municipal Corporation
KSPCB	Kerala State Pollution Control Board
MBBR	Moving bed bio reactor
MBR	Membrane bio reactor
MDGs	Millennium Development Goals
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
NPK	Nitrogen Phosphorous Potassium
NRCD	National River Conservation Directorate
NRCP	National River Conservation Directorate

NUSP	National Urban Sanitation Policy
OFMSW	Organic Fraction of Municipal Solid Wastes
O&M	Operation and maintenance
PST	Primary Settling Tank
RSF	High return sludge flow
RUIDP	Rajasthan Urban Infrastructure Development Projects
SBR	Sequential batch reactor
SDT	Solids detention time
SRT	Solid retention time (θ_c)
SS	Suspended solids
SST	Secondary Settling Tank
STP	Sewage Treatment Plant
TSS	Total suspended solids
UASB	Up-flow anaerobic sludge blanket
UDH, GoR	Urban Development & Housing Department, Government of Rajasthan.
WSP	Waste Stabilization Pond

LIST OF NOTATIONS

Q_{pi}	Influent flow rate to PST
Q_{rp}	Return sludge flow rate to PST,
Q_{pe}	Supernatant flow rate from PST to AT,
Q_{pu}	Underflow flow rate from PST (primary sludge)
X_{pi}	Solid concentration in influent to PST
X_{rp}	Solid concentration in return/excess sludge (added to PST
X_{pe}	Solid concentration in supernatant of PST
X_{pu}	Under flow solid concentration of PST
Q	Influent flow rate
S°	Influent BOD_5
θ_c	Sludge age
S	Influent BOD_5
X_t	Solid produced

CHAPTER 1

INTRODUCTION

The chapter presents wastewater treatment operations, activated sludge process, history of treatment processes, and description of the study area followed by origin of the problem, research objectives and structure of the thesis.

As the population is growing, quantity of sewage generated in urban areas is increasing. Sewage treatment plants (STPs) which are already operating are facing new challenges. Thus, a large scale study of the performance of these STPs is imperative. Declining performance of STPs also requires evolution of newer methods to diagnose the problems and accordingly improve them in an environmentally sustainable manner. Present doctoral research work aims at studying the performance of an existing STP of an urban area from a new approach using energy consumption and routine performance evaluation data to derive kinetic values of biological treatment, diagnosing troubles in operation and brings out a novel modification in the recirculation method of return sludge to improve the energy performance of the plant.

1.1 Wastewater treatment options

Wastewater treatment is achieved in a series of steps; each accomplished using one or more unit operation(s) and/ or treatment process(s). The major treatment steps are:

- Preliminary treatment - Removes materials that could damage plant equipment or would occupy treatment capacity without being treated.
- Primary treatment - Removes settleable and floatable solids (may not be present in all treatment plants).

- Secondary treatment - Removes BOD associated with dissolved and colloidal suspended organic matter, mostly by biological action. Organics are converted to stable solids, carbon dioxide and microbial cells.
- Tertiary treatment- Removes microorganisms to reduce the possibility of disease transmission when the treated water is discharged and/or removes nutrients like nitrogen and phosphorus to prevent eutrophication of receiving water bodies.

1.2 Activated sludge process

There is no single system capable of adjusting to all the varying conditions encountered in the field while having the ability to meet all the demands of high quality effluent, energy saving, economy and environmental friendliness. Among the aerobic processes, activated sludge process and its variants represent the most widespread technology used for wastewater treatment in India. The activated sludge process is a biological wastewater treatment method in which microorganisms are coalesced together to form sludge flocs. The flocs develop spontaneously when the wastewater is aerated. Most of the impurities in the wastewater are suitable nutrients for assimilation by the bacterial cells. This process is based on aeration of wastewater with flocculating biological growth (secondary sludge), followed by separation of treated wastewater from this growth. Part of the generated biological solids is then wasted or processed further as per regulations, and the remainder is returned to the system (aeration tank). Usually, the separation of the sludge from the treated wastewater is performed by settling (gravity separation) but it may also be done by flotation and other methods.

The scale of activated sludge process plants ranges from package plants for a small community to huge plants serving big cities. Wastewater treatment plants operating on activated sludge process are generally able to fulfill stringent effluent criteria. ASP was initiated by the British and American engineers at the beginning of twentieth century as an alternative to fixed-film systems. The experiments with wastewater aeration did not provide the expected results until Ardern and Lockett (1914) introduced a recycle of suspension formed during the aeration period (so called return sludge). The suspension, known as activated sludge, is in fact an active biomass responsible for the improvement of treatment performance.

Another important property of this biomass is that it contains extra cellular polymers that have a good flocculation property. This property has not been studied much and has thus been evaluated and utilized in the present research for the improvement of Plant performance in terms of removal of TSS and BOD_5 from primary settling tank.

The activated sludge process is in operation in hundreds of full-scale sewage treatment works and several billion gallons of sewage are treated every day. Activated sludge plants are now operated all over the world, extending from Helsinki, Finland to Bangalore, India; from Flin Flon, Manitoba, Canada to Glenelg, Australia; and from Golden Gate Park, San Francisco to Johannesburg, South Africa. Huge plants are in operation at London, New York, Chicago, Cleveland and Milwaukee. This astounding growth in the past twenty-five years is unparalleled in the history of sewage treatment, and must be ascribed to the fact that the activated sludge process is in harmony with the speed and science of modern life. Sewage treatment works in our modern cities can no longer be obnoxious or inefficient. They must be free from odour, occupy limited area, and be amenable to scientific control (Cooper, 2000).

Municipal STPs are one of the major consumers of energy in national energy system and the cost of this power consumption is a significant part of the operating costs of the plants. In wastewater treatment plants, it is very difficult to make power savings in general because the process is continuous, and, on the other hand the treatment technology is based on processes (physical, chemical and especially biological) that cannot be switched off or disconnected from the main supplies.

For upgrading an existing STP, the performance appraisal may play a big role especially if it has to be augmented to handle higher hydraulic and organic loads or work at an enhanced efficiency through process modifications (Bretscher, 2005). A detailed performance analysis of an STP using the routine records of organics removal and the apportionment of power consumption for individual units can be very useful for gaining insight of plant operations and subsequently, troubleshooting as required for improving performance.

1.3 Study area

The present study was carried out at STP Delawas, Jaipur which has a designed capacity of 62.50 million L/day (MLD), and the treatment is based on conventional activated sludge process with diffused aeration system. The STP is in operation since September 2006. The present case study is an attempt to develop protocols for continuous assessment and diagnostics for STP in order to optimize the process both in terms of organics removal as well as energy consumption.

Figure 1.1 shows the general sewerage system of the south city area on the map of Jaipur; Figure 1.2 presents the general layout of the STP, and Figure 1.3 shows a photograph of the inlet of the STP. Larger size layout, hydraulics flow drawing with few photographs of Plant studied shown at Appendix 2

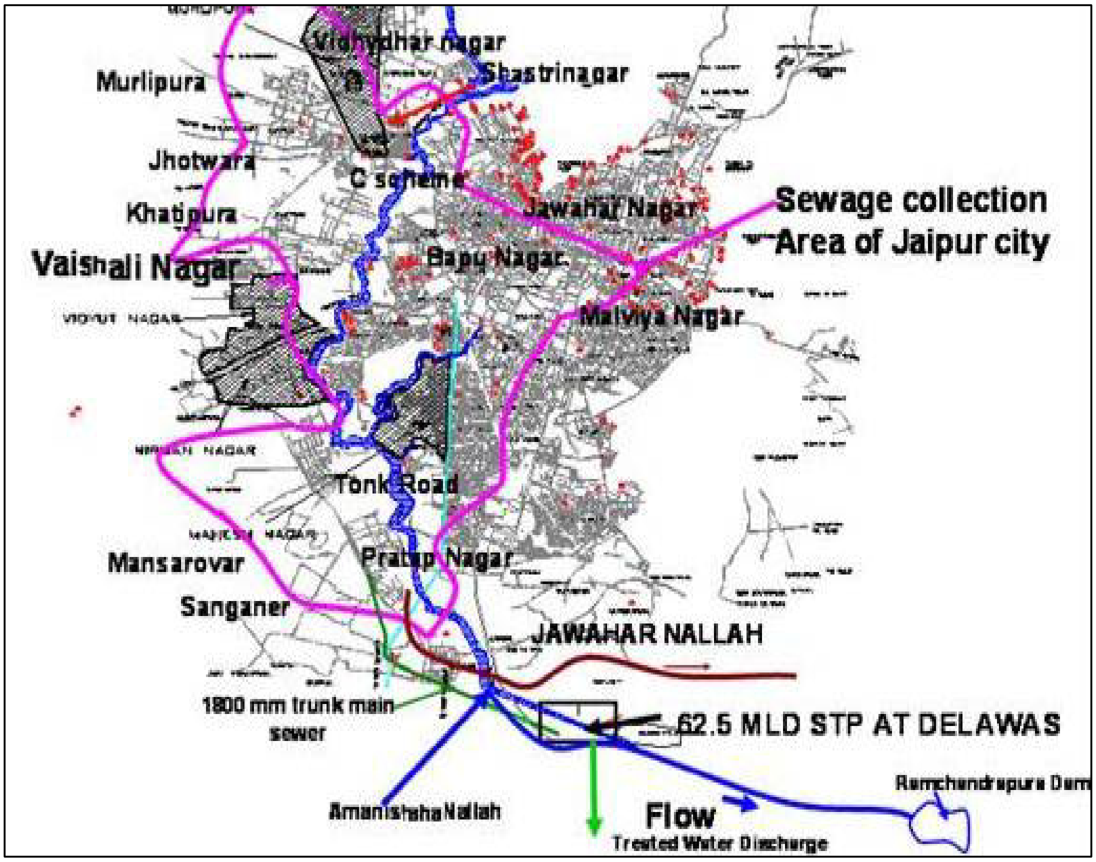


Figure 1.1 Sewerage coverage area south Jaipur

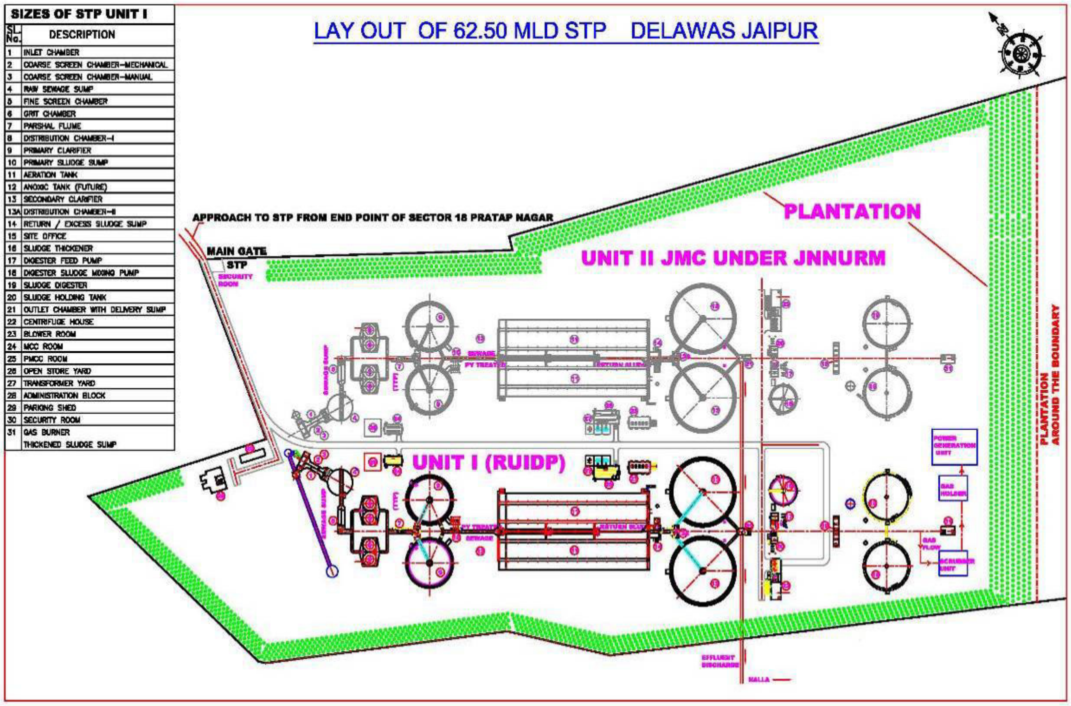


Figure 1.32 General layout of STP

Figure 1.3 Inlet unit STP, Delawas (Study area)

In the biological treatment of sewage, considerable amount of sludge is generated by sedimentation in the form of primary and secondary sludges that require proper handling. An effective solution to reduce or even eliminate energy costs in STPs is anaerobic digestion of the sludge to produce biogas and to use it for the plant's own energy needs. This can prove to be very advantageous for all medium and large STPs especially where sewage has a very high biological load coupled with a favorable COD: BOD ratios. Biogas from anaerobic digestion of biological wastes is a renewable resource and hence a clean form of energy. The major energy fraction of biological sludges from STPs comes from the primary sludge, as it consists of more easily digestible carbohydrates and fats, compared to activated sludge, which comprises complex carbohydrates, proteins and long chain hydrocarbons (Zhang, (2010). Hence, biogas is more easily produced from primary sludge. Thus, wherever any energy generation unit based on anaerobic digestion of sludges exists in an STP, any extra removal of suspended organics from the primary clarifier can add greatly to the energy generation potential of the plant. At the same time, an equivalent amount of extra energy would be saved as these organics will not reach the aeration tank and hence would not require aerobic oxidation. The secondary sludge contains higher amounts of extracellular polymers, which possess excellent flocculation characteristics which can be used for the enhancement of settling performance at PST.

Deriving clues for the aforementioned analysis, attempt has been made to improve the performance of PST through controlled mixing of sewage entering it with excess secondary sludge in different proportions to enhance settling of colloidal particles. Digested sludges from anaerobic and aerobic sludge digesters of STP Delawas (Jaipur South) and STP Brahmapuri (Jaipur North) respectively were tried for this purpose, with the latter giving excellent results. The conditioned return sludge (after brief aeration) was found to be very useful in increasing the efficiency of PST in terms of both TSS and BOD removal, indicating huge benefits in terms of energy efficiency of the process. The suggested flow scheme of STPs can be assessed for its performance against other aerobic suspended growth processes such as SBR, MBBR, MBR etc. especially wherever energy generation provision exists or is envisaged.

Funds and uninterrupted power supply required for operation & maintenance of the STP are always issues with urban local bodies. Therefore, there is a need to find out ways to make the STP self-sustainable in terms of operation and maintenance (O&M) cost. The efficient operation and maintenance of STPs depends on uninterrupted energy supply, skilled manpower and preventive and regular maintenance. In STPs, energy cost for treatment per MLD of sewage constitutes 65% - 75% of the total O&M cost of the plant, depending on the process (ASP/MBBR/MBR). This indicates that there is significant variability in unit power consumption and scope exists for its optimization. It was theorized that a micro analysis of the performance of aeration tank for secondary treatment (the major power consumer) and that of PST (the major power production comes from primary sludge) may bring out a strategy for energy optimization of the STP without modifying the design of the existing units.

Hence, this study was designed to carry out performance appraisal of the process for developing diagnostics, and for enhancement of the energy yield by attempting enhanced settling in PST using flocculent properties of excess sludge (both raw and modified) to attain long term sustainability.

1.4 Objective of thesis work

The present research work was undertaken with the following specific objectives:

- To analyze performance of ASP in terms of BOD_5 and TSS removal, kinetic values of biological process, as well as its energy performance.
- To devise feasible interventions for reduction in O&M cost of STP especially in power consumption
- To study the effect of excess sludge (with and without modification) addition as a flocculent in primary clarifier and determine optimal regime of mixing for removal of organics through settling and
- To assess the energy balance of the sewage treatment plant under different scenarios and suggest measures for the maximum returns in terms of energy balance.

The research work in this thesis is mainly focused on using the available process data for improvement in process efficiency of secondary treatment unit and to achieve higher efficiency of primary settling tank (PST) by which operating costs may be reduced. The output is expected to offer a solution to the operators and designers to derive optimum benefits of the byproduct (microbial sludge) obtained during operation of treatment units, especially to make STP self-sustainable in terms of O&M.

1.5 Structure of the thesis

The chapter-wise outlay of the thesis is as follows:

Chapter 1 presents the details of the wastewater treatment operations, Activated sludge process, history of treatments process, and brief about study area, followed by research objectives and thesis chapters details.

Chapter 2 presents a comprehensive review of the relevant literature. It brings out the gaps in the existing knowledge and outlines the contributions of the literature in designing the present study.

Chapter 3 describes the salient features of STP, Delawas along with its biological performance analysis using routine records in terms of biological parameters and energy balance.

Chapter 4 incorporates the experimental set-up used, materials and methodology. It also explains the use of excess sludge as readily available low cost and risk-free flocculent to enhance the performance of primary settling tank. The results have been interpreted to suggest an optimum strategy for achieving favorable energy balance in the process.

Chapter 5 presents the conclusions of the research findings including the contribution of the present research. It also discusses the scope for future research in the area.

CHAPTER 2

LITERATURE REVIEW

This chapter presents brief details of the municipal sewage, impurities in municipal sewage, typical treated effluent standards, classification of common wastewater treatment processes, activated sludge process and a comprehensive review of relevant literature.

The available literature and theoretical considerations with present scenario in India and abroad, along with the history of treatment and problem in their operations and work done so far for performance enhancement of the STPs is presented. Recent studies on performance evaluation of the STPs are elucidated to brings out the gaps in the existing knowledge.

2.1 Municipal wastewater

Municipal wastewater is usually conveyed in a combined sewer or sanitary sewer, and treated at a wastewater treatment plant. Treated wastewater is discharged into receiving water body via an effluent sewer. Sewage includes domestic, municipal, or industrial liquid waste products disposed of, usually via a pipe or sewer (sanitary or combined), sometimes in a cesspool emptier. Sewerage is the physical infrastructure, including pipes, pumps, screens and channels etc. used to convey sewage from its origin to the point of eventual treatment or disposal. It is found in all types of sewage treatment plants, with the exception of septic systems, which treat sewage on-site. Modern sewerage systems began to appear in the 19th century, when existing storm sewers were enlarged to carry wastes to nearby waterways. Municipal sewage treatment was slowly adopted in the 20th century. The growing size of cities and the pollution caused by untreated sewage forced the passage of the legislation that set quality standards for treated sewage and funded sewage treatment facilities (Discovery Communications, LLC (2011).

2.2 General impurities in municipal wastewater

Municipal wastewater, general impurities (contaminants) and their significance are summarized in Table 2.1:

Table 2.1 Contaminants, their significance and origin of wastewater (Metcalf and Eddy Inc, 1991)

Contaminant	Significance	Origin
Settleable solids (sand, grit)	Settleable solids may create sludge deposits and anaerobic conditions in sewers, treatment facilities or open water.	Domestic, runoff
Organic matter (BOD); Kjeldahl nitrogen	Biological degradation consumes oxygen and may disturb the oxygen balance of surface water; if the oxygen in the water is exhausted, anaerobic conditions, odor formation, fish kills and ecological imbalance will occur.	Domestic, Industrial
Pathogenic microorganisms	Severe public health risks through transmission of communicable water borne diseases such as cholera	Domestic
Nutrients (N and P)	High levels of nitrogen and phosphorus in surface water will create excessive algal growth (eutrophication). Dying algae also contribute to organic matter.	Domestic, rural run-off, Industrial
Micro-pollutants (heavy metals, organic compounds)	Non-biodegradable compounds may be toxic, carcinogenic or mutagenic at very low concentrations to plants, animals, and humans. Some may bioaccumulate in food chains, e.g. chromium (VI), cadmium, lead, most pesticides and herbicides, and PCBs	Industrial, rural run-off (pesticides)
Total dissolved solids (salts)	High levels may restrict wastewater use for agricultural irrigation or aquaculture	Industrial, (salt water intrusion)

2.3 Typical treated effluent standards

As per Schedule 1 (Rule 3) of Central Pollution Control Board of India, typical treated effluent standards as a function of the intended use of the receiving waters, effluent (treated wastewater) should meet the specified criteria (Table 2.2):

Table 2.2 General Standards for discharge of environmental pollutants (Environment Protection Rules 1980 CPCB, Government of India)

Parameters		Standards			
		Inland surface water	Public sewer	Land for irrigation	Marine/coastal area
1.	Color and Odor	See 6 of Annexure I		See 6 of Annexure I	See 6 of Annexure I
2.	Suspended Solids mg/L, max.	100	600	200	(a) For process waste water (b) For cooling water effluent, 10 per cent above total suspended matter of influent.
3.	Particle size of suspended solids	Shall pass 850 micron IS Sieve	-	-	(a) Floatable solids, solids max. 3 mm (b) Settleable solids, max 856 microns
4.	pH value	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0
5.	Temperature	Shall not exceed 5°C above the receiving water temperature			Shall not exceed 5°C above the receiving water temperature
6.	Oil and grease, mg/L max.	10	20	10	20
7.	Total residual chlorine, mg/L max.	1.0	-	-	1.0
8.	Ammonical nitrogen (as N), mg/L, max	50	50	-	50
9.	Total Kjeldahl	100	-	-	100

Parameters		Standards			
		Inland surface water	Public sewer	Land for irrigation	Marine/coastal area
	nitrogen (as N) mg/L, max.				
10.	Free ammonia (as NH_3), mg/L, max.	5.0	-	-	5.0
11.	Biochemical oxygen demand (3 days at 27°C), mg/L, max.	30	350	100	100
12.	Chemical oxygen demand, mg/L, max.	250	-	-	250
13.	Arsenic (as As).	0.2	0.2	0.2	0.2
14.	Mercury (as Hg). mg/L, max.	0.01	0.01	-	0.01
15.	Lead (as Pb) mg/L, max.	0.1	1.0	-	2.0
16.	Cadmium (as Cd) mg/L, max.	2.0	1.0	-	2.0
17.	Hexavalent chromium (as Cr^{+6}), mg/L, max.	0.1	2.0	-	1.0
18.	Total chromium (as Cr) mg/L, max.	2.0	2.0	-	2.0
19.	Copper (as Cu) mg/L, max.	3.0	3.0	-	3.0
20.	Zinc (as Zn) mg/L, max.	5.0	15	-	15
21.	Selenium (as Se) mg/L.	.	0.05	-	0.05
22.	Nickel (as Ni) mg/L, max.	3.0	3.0	-	5.0
23.	Cyanide (as CN) mg/L, max.	0.2	2.0	0.2	0.2

Parameters		Standards			
		Inland surface water	**Public sewer**	**Land for irrigation**	**Marine/coastal area**
24.	Fluoride (as F) mg/L, max.	2.0	15	-	15
25.	Dissolved phosphates (as P), mg/L, max.	5.0	-	-	-
26.	Sulphide (as S) mg/L, max.	2.0	-	-	5.0
27.	Phenolic compounds (as C_6H_5OH) mg/L, max.	1.0	5.0	-	5.0
28.	Radioactive materials	-	-	-	-
	(a) Alpha emitters micro curie mg/L, max.	10^{-7}	10^{-7}	10^{-8}	10^{-7}
	(b) Beta emitters micro curie mg/I	10^{-6}	10^{-6}	10^{-7}	10^{-6}
29.	Bio-assay test	90% survival of fish after 96 hours in 100% effluent	90% survival of fish after 96 hours in 100% effluent	90% survival of fish after 96 hours in 100% effluent	90% survival of fish after 96 hours in 100% effluent
30.	Manganese	2 mg/L	2 mg/L	-	2 mg/L
31.	Iron (as Fe)	3 mg/L	3 mg/L	-	3 mg/L
32.	Vanadium (as V)	0.2 mg/L	0.2 mg/L	-	0.2 mg/L
33.	Nitrate Nitrogen	10 mg/L	-	-	20 mg/L

These standards are applicable for industries, operations or processes other than those industries, operations or process for which standards have been specified in Schedule of the Environment Protection Rules, 1989.

2.4 Classification of common wastewater treatment processes

The basic function of the wastewater treatment plant is to speed up the natural processes by which water purifies itself. In earlier years, the natural treatment process in streams and lakes was adequate to perform basic wastewater treatment. As our population and industry grew to their present size, increased levels of treatment prior to discharging domestic wastewater became necessary.

Classification of common wastewater treatment processes is listed in Table 2.3.

Table 2.3 Classification of common treatment processes (Arceivala, 2003)

Primary	Secondary	Tertiary	Advanced
Bar screen	Activated sludge	Nitrification	Chemical treatment
Grit removal	Extended aeration	Denitrification	Reverse osmosis
Primary sedimentation	Aerated lagoon	Chemical precipitation	Electrodialysis
Comminution	Trickling filter	Disinfection	Carbon adsorption
Oil/fat removal	Rotating bio-discs	(Direct) filtration	Selective ion exchange
Flow equalization	Anaerobic treatment/UASB	Chemical oxidation	Hyperfiltration
pH neutralization	Anaerobic filter	Biological P removal	Oxidation
Imhoff tank	Stabilization ponds	Constructed wetlands	Detoxification
	Constructed wetlands	Aquaculture	
	Aquaculture		

Expected efficiency of various treatment units are summarized in Table 2.4.

Table 2.4 Expected efficiency of various treatment units (Arceivala, 2003)

S.No.	Process	SS, mg/L	BOD, mg/L	Total Coliform, MPN/100 mL
1	Primary treatment (Sedimentation)	45-60	30-45	40-60
2	Chemical treatment	60-80	45-65	60-90

S.No.	Process			SS, mg/L	BOD, mg/L	Total Coliform, MPN/100 mL
3	Secondary treatment					
	i	Standard trickling Filters		75-85	70-90	80-90
	ii	High rate trickling filters				
	a	Single stage		75-85	75-80	80-90
	b	Two stage		90-95	90-95	90-60
	iii	Active sludge Plants		85-90	85-95	90-96
	iv	Extended aeration		90-95	85-98	90-96
4	i	a	Stabilization ponds (Single Cell)	80-90	90-95	90-95
		b	Stabilization Ponds (Two Cell)	90-95	95-97	95-98
5	UASB			60-70	60-70	80-90
6	SBR			95-98	95-98	95-98
7	MBBR			95-98	95-98	95-98
8	MBR			95-98	95-98	95-98

Tertiary treatment is adopted when reuse of effluent for industrial purpose is contemplated or when circumstances dictate the requirement of higher quality effluents.

In general, activated sludge process based treatment plants encompass a variety of mechanism processes and use dissolved oxygen to promote the growth of biological floc that substantially removes organic material. Biological floc, is an ecosystem of living biota that subsists on nutrients from the inflowing primary settling tank (or clarifier) effluent. These nutrients are mostly carbonaceous dissolved solids that undergo aeration to be broken down and biologically oxidized or converted to carbon dioxide.

To reduce the operational cost, there is a need to find out a way so that it is economical to operate and improve the efficiency of various units of the process.

2.5 Land requirement and capital cost for STPs

The criteria for selection of treatment process, mainly depends on quantity of wastewater, characteristics of waste to be treated, degree of treatment required, land availability, efficiency and performance of the technology, reliability of the technology, institutional manageability, financial sustainability, application in reuse schemes and regulatory determinants etc. The technology of treatment must be able to remove the organic contaminants either aerobically (in the presence of Oxygen) or anaerobically(in the absence of oxygen) along with other contaminants. Similarly, the pathways and fate of the removed pollutants after treatment should be analyzed, especially with regard to the disposal options for the sludges in which the micro-pollutants tend to concentrate. The process available for treatment, land requirement and capital cost considered by Urban Development Department, Government of Rajasthan, Jaipur, India for the treatment of municipal wastewater is summarized in Table 2.5 (RUIDP, 2011)

Table 2.5 Land requirement and capital cost for STPs

S.No.	Treatment process	Land requirement per MLD (in Hectares)	Capital cost per MLD based on 5 to 10 MLD capacity (Rs. in lacs)
1	Conventional ASP	0.23	105-90
2	Extended aeration	0.15	105-90
3	Waste stabilization pond (pumping is at STP)	0.93	65-45
4	Facultative aerated lagoons	0.14	85-65
5	Up-flow Anaerobic Sludge Blanket (UASB) followed by Facultative Pond (in case pumping is at STP)	0.65	90-70
6	Trickling filter	0.19	75-65
7	Sequential batch reactor	0.09	115-95
8	Moving bed bio reactor (MBBR)	0.075	130-100
9	Membrane bio reactor (MBR)	0.075	135-115

2.6 Power and O&M costs

Most of the towns of Rajasthan are of population ranging from 50,000 - 90,000. Generally, STP's are being constructed in modules and replication of earlier was done in later stage if the process was functioning satisfactory. The capacities to be proposed in towns are generally in the range of 5 to 10 MLD. Based on standard books, published literature and field experience of various agencies, expected power consumption and O&M costs per MLD for 5 to 10 MLD capacity STP's for various treatment processes are summarized in Table 2.6.

Table 2.6 Power consumption and O&M costs for 5 - 10 MLD Sewage treatment plants (UDH, Raj. 2011)

S.No.	Treatment process	Power charges / month/ (Rs. in lacs)	O&M charges per month (Rs. in lacs)	Total cost / month charges (Rs. in lacs)	Remarks
1	Conventional ASP	1 - 0.85	0.55 - 0.325	1.55 - 1.18	Less area requirement. Power consumption is higher. Generally proposed where treated water is to be disposed-off in a water body.
2	Extended Aeration	1.0 - 0.90	0.55 - 0.325	1.65 - 1.125	Less area required than ASP. Power consumption is higher than ASP. Generally in use where treated water is to be disposed off in a water body.
3	Waste stabilization pond (pumping is at STP)	0.25 - 0.2	0.25 -0.18	0.50 - 0.38	Larger area is required. Very small power and O&M cost. Generally proposed where land is easily available and treated water is to be discharged on land.
4	Facultative aerated lagoons	1.00 - 0.70	0.50 - 0.35	1.50 - 1.05	Land requirement is lesser than WSP. Where low BOD wastewater is to be treated, the process is proposed.

S.No.	Treatment process	Power charges / month/ (Rs. in lacs)	O&M charges per month (Rs. in lacs)	Total cost / month charges (Rs. in lacs)	Remarks
5	UASB followed by Facultative Pond (in case pumping is at STP)	0.30 - 0.20	0.30 - 0.20	0.60 - 0.40	Land requirement is lesser than WSP. Power requirement is also less. O&M require specific attention. Treated wastewater can be discharged on land.
6	Trickling filter	1.0 - 0.85	0.55 - 0.325	1.55 - 1.18	Land requirement is lesser than ASP. Power requirement is almost equal to ASP. O&M require specific attention. Environmental nuisance caused due to flies.
7	Sequential batch reactor	1.0 - 0.8	0.55 - 0.326	1.65 - 1.13	Land requirement is lesser than ASP. Better quality treated water. It can be used for cleaning washing etc. after chlorination.
8	Moving bed bio reactor (MBBR)	0.25 - 0.2	0.25 - 0.18	0.50 - 0.38	It is modified version of ASP. Less area is required. Generally used for smaller capacity 1-5 MLD. Treated quality is almost same as in SBR. More care is required during O&M due to media removal & cleaning.
9	Membrane bio reactor (MBR)	1.00-0.70	0.50-0.35	1.50-1.05	It is new technology, area requirement is lesser than SBR. Generally proposed for small capacities. More care is required during O&M due to membrane repairs and replacement.

2.7 Process selection

The availability of land and value of land at proposed site is an important aspect in selection of treatment process. The capital cost available, capacity to bear power charges, O&M cost and availability of skill manpower also play a significant role in selection of treatment process. Guidelines for selection of treatment process are summarized in Table 2.7.

Table 2.7 Selection of treatment process and required treated wastewater parameters

S. No.	Treatment process	Required treated waste water (effluent) parameters(mg/L)	Remarks
1	Conventional ASP	$BOD_5 \leq 30$, $SS \leq 50$	Process may be proposed, if land area available is less, expensive and near to residential area. Treated water is to be disposed-off in a water body. If the capacity of STP is more, power from sludge may be generated to run the plant and/or effluent may be reused for industrial and other purposes.
2	Extended aeration	$BOD_5 \leq 30$, $SS \leq 30$	Process may be proposed, if land area is less, expensive and near to residential area. Treated water is to be disposed-off in a water body and/or effluent may be reused for industrial and other purposes.
3	Waste stabilization pond (pumping is at STP)	$BOD_5 \leq 100$, $SS \leq 100$	Process may be proposed, if land area is easily available, not expensive and not near to residential area. Treated water is to be disposed-off on land or to be used in irrigation.
4	Facultative aerated lagoons	$BOD_5 \leq 30$, $SS \leq 100$	Process may be proposed, if land area is less, expensive and not so near to residential area. Treated water is to be disposed off in a water body. Nowadays it is generally not proposed for municipal wastewater treatment.
5	UASB followed by Facultative pond (in case pumping is at STP)	$BOD_5 \leq 100$, $SS \leq 100$	Process may be proposed, if available land area is less than required for WSP, moderately expensive and not near to residential area. Treated water is to be disposed-off on land or to be used in irrigation. Treated wastewater is to be discharged on land.

S. No.	Treatment process	Required treated waste water (effluent) parameters(mg/L)	Remarks
6	Trickling filter	$BOD_5 \leq 30$, $SS \leq 100$	Process may be proposed, if land area is less, expensive and not near to residential area. But environmental nuisance is more at site than other process, due to flies.
7	Sequential batch reactor	$BOD_5 \leq 10$, $SS \leq 10$	Process may be proposed if land area is less, expensive and near to residential area. Treated water is to be disposed-off in a water body or to be used for industrial purposes.
8	Moving bed bio reactor (MBBR)	$BOD_5 \leq 10$, $SS \leq 100$	Process may be proposed, if land area is less, expensive and near to residential area. Treated water is to be disposed-off in a water body or to be recycled for industrial purposes. It is modified version of ASP. Better for small capacity.
9	Membrane bio reactor (MBR)	$BOD_5 \leq 10$, $SS \leq 100$	Process may be proposed, if land area is less, expensive and near to residential area. Treated water is to be disposed off in a water body or to be used for industrial purposes. It is modified version of ASP. Better for small capacity.

2.8 Activated sludge process

Activated sludge process (ASP) comprises of primary treatment unit which includes inlet unit, coarse screens, pumping of required head, fine screens and grit separators wherein inorganic impurities are removed. These primary units are generally common in all processes. Further, after flow measurement unit, primary settling tanks are used for removal of suspended solids and suspended BOD using gravity phenomena. Generally, about 30-40% suspended solids and 25-35% BOD can be removed in Primary Settling Tank (PST). The secondary treatment unit so called heart of the Activated Sludge Process (ASP) is aeration tank together with the settling tank/ clarifier wherein the bulk of the treatment is provided, employing microbes/bacteria for the process. The main function of the aeration tank is to maintain a high population of microbes. This mixture is called Mixed Liquor Suspended Solids (MLSS). The mixed liquor is passed onto the secondary clarifier tank, where the microbes are made to settle at the bottom. The settled microbes are recycled back to the aeration tank to be retained for a long period within the system. The secondary clarifier is employed to thicken the settled biomass in order to produce a thick underflow and clear supernatant water (secondary level treated wastewater) in the overflow from the clarifier. The clarifier tank is only a passive device wherein all the actions occur due to gravity. The thick biomass is recirculated back to the aeration tank.

2.9 Sludge handling

Biological treatment of wastewater perforce produces excess biological solids due to the growth and multiplication of bacteria and other microorganisms in the system. The excess biomass thus produced needs to be bled out of the system, and disposed-off efficiently. This is a five-step process: sludge removal, storage, conditioning, dewatering and disposal. Sludge is removed ("bled") from the system from the sludge recirculation pipeline (through a branch). The sludge is in the form of a thick slurry. The sludge treatment and disposal route is considered at the beginning stage in any process design. The digestion of sludge can be done aerobically or anaerobically. In aerobic digestion, after thickening of sludge, aeration is provided wherein the digestion takes place by aerobic bacteria and digested sludge is further sent to sludge drying beds for drying and then disposed-off further which can be used as manure. Anaerobic digestion of sludge needs more activities as it is carried out in a closed container. During digestion, in first step of hydrolysis, cell walls are ruptured and extracellular polymeric substances are degraded resulting in the release of readily available organic material for the acidogenic micro-organisms, the suspended substrate can be made more accessible for the anaerobic bacteria optimizing the methanogenic potential of the waste to be treated. Various sludge treatments such as mechanical grinding, ultrasonic disintegration, chemical treatment, thermal pre-treatment, enzymatic and microbial pre-treatment are available. Nowadays, the sludge treatment is becoming a source of energy and considered as waste to energy. The ever-increasing demand of energy and over exploitation of fossil fuel resources has led to several environmental concerns. To counter these environmental problems, governments, around the world are going in for clean energy technologies, stringent waste disposal system and supporting the energy generation from waste and other non-conventional or renewable sources. With the quantities of waste generated by the urban and rural population and industrial units, some industrial units as well as some municipal bodies have initiated action in the area of Waste to Energy.

2.10 Worldwide power generation through biogas

The operation and maintenance of STPs depend on uninterrupted energy supply, skilled manpower and preventive and regular maintenance. In case of natural treatment technology, energy requirement is quite low while the conventional treatment technologies demand considerably higher amount of energy. In planning and designing treatment plants and common effluent treatment plants (CETPs), land requirement and its availability at required location is also an important aspect. In case of natural treatment processes, large area of land is required, whereas other technologies such as upflow anaerobic sludge blanket (UASB), activated sludge process (ASP), sequential batch reactor (SBR), moving bed bio reactor (MBBR), membrane bio reactor (MBR) require a lesser area as compared to natural treatment processes. The energy consumption per capita for treatment of wastewater came out to 12-15 kWh/person-year considering 80% of water @180 L per capita per day is contributing to sewage reaching to STP for treatment with a BOD generation of 50 g/d per capita.

Management and disposal of waste poses enormous problems, especially in large cities e.g., it affects the people in terms of health, affects the surface water bodies, pollute fresh water streams and ground water by industrial discharges result in depletion of existing water sources etc. Utilization of waste for power generation through appropriate technological options is perhaps one of the most appropriate propositions, since it not only generates clean energy but disposes the waste, which otherwise contributes to environmental pollution. This has captured the imagination of both the Governments as well as the private organizations all over the world. With the quantities of waste generated by the urban and rural population and industrial units, some industrial units as well as some municipal bodies have initiated action in the area of waste to energy.

In today's energy demanding life style, biogas as a typical renewable as well as eco-friendly new energy source will replace fossil fuel inevitably. Hence, how to increase biogas production is a problem of major concern in terms of environment, finance and technology. The worldwide power generation data from sewage biogas are summarized in Table 2.8

Table 2.8 World power generation at a glance during the year 2009 (Jaiswal, K M., MNIT, Jaipur 2012)

S.No.	Country	Total electricity generated (GWhE)	electricity from sewage biogas generated (GWhE)	Percent of total electricity from sewage biogas
1.	Luxembourg	6500	6	0.09
2.	The Netherlands	124000	150	0.12
3.	Czech Republic	62000	83	0.13
4.	United States of America	38763000	2400	0.06
5.	Denmark	34300	38	0.11
6.	Australia	222000	125	0.06
7.	Austria	68300	39	0.06
8.	Poland	129300	123	0.10
9.	Sweden	134500	19	0.01
10.	France	447000	45	0.01
11.	Italy	315000	20	0.01
12.	India (May 2014)	967,150	Data not found	

To present the information available on wastewater in a better way from the reviewed literature, it is divided in the following four sections:

(1) Evaluation of biological treatment process,

(2) Sludge recycling and chemical addition effects on settling.

(3) Power and land requirements of different processes.

(4) Energy recovery through bio gas.

Details of reviewed relevant literature are summarized in Table 2.9.

Table 2.9 Summary of published literature on wastewater treatment

S. No.	Author, year	Area of study	Major findings
(1) Evaluation of biological treatment process			
1	Tebbutt and Christoulas, 1975	Performance relationships for primary sedimentation	The removal of total SS is strongly affected by settling characteristics of particles. Settling characteristics of suspended particles mainly depend upon the nature of the particles and their concentration in the wastewater.
2	Levine et al., 1985	Enhancing urban environment by environmental up gradation and restoration	Particle sizes in complex mixtures of particulates of municipal wastewater includes the soluble organics and inorganics ranging in sizes from less than 0.001 μm to well over 100 μm. The size characterization of the contaminants in wastewater is the development of an improved rationale for the selection, design, and evaluation of wastewater treatment systems.
3	Tillman, 1991	Primary treatment at wastewater treatment plants	In an effectively operated primary treatment system, SS removal efficiency was typically found in the range as high as 40 to 60%, while that for BOD_5, it was 30-35%. The primary treatment cannot achieve higher levels of BOD_5 removal because majority of the organics in sewage is present either in soluble or finely divided particulate form which is not settleable.
4	Patry and Takacs, 1992	Settling of flocculent suspension in secondary clarifiers	Relationship between the average settling velocity of floc particles in the upper layers of a secondary clarifier and the concentration of suspended solids within that layer were established.
5	Odegaard, 2000	Advanced compact wastewater treatment based on coagulation and moving bed biofilm processes	Substantial portion of the pollutants in municipal wastewater appears as particulate and colloidal matter. Pre-coagulation gives very efficient pre-treatment that result in considerable saving in the total space required by the plant. The majority of organic matter present in the suspended form can be removed by solid-liquid separation using physical and chemical means.

S. No.	Author, year	Area of study	Major findings
6	Metcalf and Eddy et al.; 2003	Wastewater Engineering and Treatment	About 50-70% of SS are removed from the raw wastewater entering the treatment plant in the primary sedimentation tanks.
7	Bretscher, 2005	Enhancement of the performance of the activated sludge process	Performance of ASP may be enhanced by a higher sludge concentration or prolonged retention time in the aeration tank and in traditional ASP by extension of contact time.
8	Kumar et at., 2010	Performance efficiency of a wastewater treatment plant	Removal efficiency of BOD_5 was found to be 94.56% and that of TSS was 93.72%. BOD and TSS removal efficiencies of the primary clarifier were 30.59% and 50.61%, respectively. Study does not provide further details on enhancement of performance of STP.
9	Aslam et al., 2011	Settling of solids in primary clarifiers / storm water tanks	Maximum solids settle within the first 10 min and solids settle in the form of three fractions. These three fractions are fast settling solids, suspended solids and floatable solids.
10	Central Pollution Control Board (CPCB) India, 2013	Performance evaluation report of sewage treatment plant under NRCD	152 STPs spread over 15 states in the country having total treatment capacity of 4716 MLD, actual treatment capacity utilization in India was only 3126 MLD (66%), O & M cost per MLD of conventional (ASP) STP was estimated as Rs 30,000 per month and 2.6 kW of electricity was required per MLD sewage treatment. In STPs, energy cost for treatment of each MLD of sewage constitutes 65%-75% of the total O&M cost of the plant depending on the process (ASP/MBBR/MBR). There is a high variability in unit power consumption and scope exists for its optimization.
(2) Sludge recycling and chemical addition effects on settling			
1	Voshel and Sak, 1968	Effect of primary effluent suspended solids and BOD on activated sludge production	Primary effluent suspended solids can be controlled by the addition of an organic flocculent to the raw wastewater stream. The resulting flocculation also removes a greater portion of the BOD than is

S. No.	Author, year	Area of study	Major findings
			normally removed across the primary clarifiers. The additional removal of suspended solids and BOD both reduce excess sludge production.
2	Fall Jr., 1971	Redesigning of existing facilities to increase hydraulic and organic loading	All the waste sludge from the activated sludge system was pumped to the inlet of the primary sedimentation tank. Very little loss in efficiency of SS removal in the primary settling tank was observed
3	Heinke et al., 1980	Effects of chemical addition on the performance of settling tanks	SS removal performance of primary settling tanks can be improved by the addition of chemicals such as ferric chloride, alum, ferric chloride plus polymer, and alum plus polymer.
4	Tuntoolavest et al., 1982	Effect of activated sludge process operational conditions on sludge thickening characteristics	Waste activated sludge acts as an organic flocculent forming larger flocs due to the increased number of collisions between particles. Type of settling in the primary sedimentation tank changes from flocculent settling to hindered settling, and it becomes possible to attain higher SS removal efficiencies. In addition to the solids concentration of waste activated sludge, settling characteristics which are strongly affected by its operational conditions, can increase the primary sedimentation efficiency.
5	Tay, 1982	Development of a settling model for primary settling tanks	Settling tests by using ferric chloride and polymer to check the SS removal efficiency in primary settling tanks of three different wastewater treatment plants were performed and observed that characteristics of the solids and hydraulic characteristics are the two important factors which affected the performance and efficiency of the settling tanks.
6	Peavy et al., 1985	Sedimentation in wastewater treatment plant	In raw wastewater, the number of fine suspended particles is much larger than that of the bigger ones, and even worse, some colloidal particles may possess certain properties that would prohibit the agglomeration between various particles.

S. No.	Author, year	Area of study	Major findings
			Under the prevailing conditions normally encountered in a settling basin, efficient removal of particles less than 50 µm in diameter cannot be expected.
7	Svarovsky, 1990	Sedimentation	The particle contact and agglomeration continue during the time of sedimentation depending upon the velocity gradient available for their contact, distribution of particle size, shape, and possibly specific gravity of the particles.
8	Huang and Li, 2000	Enhanced primary wastewater treatment by sludge recycling	Sludge recycling is a viable technology for improving the primary treatment efficiency. The microbial growth imparts the needed sorptive, flocculative and enmeshment properties to the recycled sludge. When the recycled primary sludge was pre-aerated for 30 min and then mixed with raw sewage to maintain an MLSS concentration of 6000 mg/L before settling, the average removal of SS and total COD from the raw sewage were found to be 51.2% and 40.3%, respectively. Without sludge recycling (i.e., plain sedimentation), the corresponding removal efficiencies were only 46.2% and 29.9%. 48.1% of the raw sewage COD could be removed by mainly sludge flocculation/sorption and gravity settling without incurring much expenditure on the biological aeration process.
9	Yetis and Tarlan, 2002	Improvement of primary settling performance with activated sludge	The addition of waste activated sludge to raw sewage may improve primary settling efficiency depending on waste excess sludge characteristics.
10	Bahar et al., 2008	Effect of the sludge recycle ratio	HRT and the sludge recycle ratio affected the removal efficiency of COD and SVI in aerobic activated sludge system.
11	Schuyler, 2010	Low return sludge flow rates	High return sludge flow rates (RSF) affects the growth of bacteria in the system. Higher RSF decreases the solids

S. No.	Author, year	Area of study	Major findings
			detention time (SDT) which in turn corresponds to decreased time available for compaction or sludge thickening
12	Zhang, et al., 2010	Sludge treatment to increase biogas production	Major energy fraction of biological sludges from STPs comes from the primary sludge. Thus, energy generation unit based on anaerobic digestion, and extra removal of suspended organics from the primary clarifier can add to the energy generation potential from the sludge. Chemical coagulants are generally discouraged in STP as they may interfere with the biological processes of sewage as well as sludge treatment. The secondary sludge contains higher amounts of extracellular polymers, which possess excellent flocculation characteristics which can be used for enhancement of settling performance at primary treatment
13	Department of environmental protection, Pennsylvania, State 2014	Rising sludge blanket	Inadequate RAS pumping rates can result in a rising sludge blanket. The adjusted return-sludge flow rate maintains the sludge blanket as low as possible. The SVI value increased by increase in the recycle sludge was the cause of the bulking effects of the sludge.
(3) Power and land requirements of different processes			
1	Arceivala et al., 2007	Land and power requirement of different process	In conventional activated sludge, the energy consumption contribution per person came out in the range of 12-15 kWh/person-year considering 80% of water @180 L per capita per day is contributed to sewage reaching to STP for treatment and BOD of 50 g per day per person.
2	Environment Protection Agency of Climate Protection Partnerships	Water and Energy	In wastewater facilities, 10-20 % energy savings can be achieved through process optimization and 10-20 % energy savings through equipment modifications.

S. No.	Author, year	Area of study	Major findings
	Division (CPPD), 2008		
3	Menendez et al., 2010	Use of energy at wastewater treatment plants	Lower energy required to operate plants larger than 10 MGD and the energy recovery from the biogas produced with the anaerobic digestion process are a good solution in larger size plants.
4	Jangid et al., 2014	Waste to energy-Power generation	In an existing STP electrical power consumed at aeration unit is 60.50%, 13.20% for sludge handling; 21% for sewage pumping; and the rest 5.3% for screening, grit separator, primary and secondary clarifier units.
(4) Energy recovery through bio gas			
1	City River Conservation Project (C.C.R.C.P) Chennai, 2010	Energy generation from biogas from STPs	Total power production was found to be 1185 MWh from four STPs having combined capacity of 264 MLD.
2	Fdez-Guelfo et al., 2011	Biological pretreatment of industrial organic fraction of municipal solid wastes (OFMSW)	To reduce or even eliminate energy costs in STPs, anaerobic digestion of the sludge may be employed to produce biogas and to use it for the plant's own energy needs. Laboratory-scale experiments with mature compost as biological agent, 2.5% (v/v) of inoculation percentage and 24 h as incubation period. The anaerobic digestion efficiency of the industrial OFMSW, with and without pretreatment, was evaluated for a solid retention time of 15 days. The organic matter removal percentage, in terms of eliminated dissolved organic carbon and volatile solids, was increased up to 61.2% and 35.3% respectively over the control without pretreatment. As consequence, the biogas and methane production were improved up to 60.0% and 73.3% respectively. The highest cumulative biogas and methane production under anaerobic digestion were obtained with pretreated waste. The results showed that biological pretreatment with mature

S. No.	Author, year	Area of study	Major findings
			compost, followed by dry-thermophilic anaerobic digestion were the best results for stabilizing the industrial OFMSW.
3	Degremont India Ltd, New Delhi, 2013	Energy from bio gas at Rithala New Delhi, India	2 MW power produced from an STP of 140 MLD.

2.11 Performance enhancement of PSTs

Performance evaluation of wastewater Treatment Plants of Municipal wastewater / Common Effluent treatment plants is usually conducted in many countries. The purpose of evaluation studies is to find out the performance of individual process units of STPs and suggest ways to improve the efficiency of those plants which are not performing well.

Plants, which are not performing efficiently or working on low efficiency, even those were installed in accordance to the standards Conventional System for treatment of Wastewater. Performance appraisal practice of existing treatment plant units is effective in generation of additional data which can also be used in the improvement in the design procedures to be followed for design of these units. Existing facilities can be made to handle higher hydraulic and organic loads by process modifications, whereas meeting higher treatment requirements usually requires significant expansion and/or modification of existing facilities. There are studies about the performance of primary sedimentation tanks. All had a common starting point, that is, to increase the removal SS content. They all achieved this by adding a flocculent to the raw wastewater. The studies including the addition of chemicals like ferric chloride, alum, lime and polymers showed that addition of these chemicals improves SS, BOD and phosphorus removal.

Recirculation of waste activated sludge to the inlet of the primary settling basins may offer valuable increase in the performance of primary settling; but there is limited information on the subject. Thus, the purpose of this study was to investigate the effects of mixing of different concentrations digested sludge (aerobically/ an-aer obically), excess sludge direct from secondary clarifier with different concentrations and in different volumes to find out the effect of this on the performance of the primary settling basin.

CHAPTER 3

BIOLOGICAL PERFORMANCE ANALYSIS OF STP

This chapter presents the salient features of STP, Delawas along with its biological performance analysis using routine records in terms of biological parameters and energy balance.

3.1. Salient features of STP Delawas unit-I

Sewerage coverage area of south zone of Jaipur city starts from Vidhyadhar Nagar in the north to Pratap Nagar, Sanganer of south part of the city. The farthest point is about 25 km from STP and nearest is 1 km from STP. There is no provision for intermediate pumping in sewerage network up to the STP due to the favourable topography of the city. The Main trunk sewer reaching the STP site is 1800 mm in diameter laid at a slope of 1:1200, with a design capacity of 250 MLD peak flow of sewage for treatment with conventional ASP based STP at Delawas.

The STP was designed for a capacity of 62.50 MLD and the treatment is based on conventional activated sludge process with diffused aeration system. It is in operation since September 2006. It was constructed under supervision of a Government agency, Rajasthan Urban Infrastructure Development Project (RUIDP), Rajasthan under Asian Development Bank funded scheme. To optimize power consumption, a variable frequency drive (VFD) has been provided which is governed through programmed feedback circuit based on dissolved oxygen (DO) levels maintained in the bulk aeration reactor. Power is generated from the biogas obtained from anaerobic sludge digesters through a power plant of 1.0 MW capacity (including a 0.5 MW plant as standby unit) installed in 2008 and commissioned in December 2009. Figures 3.3 and 3.4 show the overview of the STP and its power generation.

Figure 3.1 Overview of STP

Figure 3.2 Overview of power generation unit with gas holders

3.2. Description of the STP

The sewage reaching the STP through an 1800 mm diameter RCC trunk sewer, is collected in the inlet chamber from where it passes through the coarse screens, and further gets collected in a sump from where it is pumped up to a channel over its top to allow an effective head of 7 m to maintain flow through various units under gravity. From the channel it passes through fine screens followed by grit removal unit and Parshall flume for flow measurement. After the flow measurement unit, it passes from primary settling tanks where sewage retains for a period of 2.25 h. The supernatant of primary clarifier is collected through double weir launders and through a channel it flows to aeration tank. In aeration tank, the return sludge is mixed at inlet of the tank and air is provided through diffused aeration system laid in the bottom of tank and connected with pipes from blower room. The aeration tank retention period is designed for 6 h. After passing from aeration tank, the oxidized sewage flows to secondary clarifier and allowed to settle for a period of 2 h. The supernatant is the secondary level treated wastewater, which is also collected through double weir launder and disposed of in a nearby drain, from where it is being used by farmers free of charge.

The primary sludge is collected in a tank and pumped to a gravity thickener and secondary excess sludge is pumped to a mechanical thickener. After thickening both the sludges are collected into a sludge holding sump and then pumped to anaerobic digesters for treatment. There is sludge mixing arrangement through centrifugal pumps, which suck the sludge from the bottom of the digesters and pump it to different inlet points of the digester above HFL. During anaerobic digestion the gases produced were flared from September 2006 to November 2009 before being used to generate power through gas engine since December 2009.

The execution, commissioning and initial O&M of the plant was carried out by M/s VA TECH WABAG Ltd Chennai, who were also working as operating agency since its commissioning in year 2006. The authority responsible for operation is Jaipur Municipal Corporation (JMC). As used now in other STPs, a variable frequency drive (VFD) was also provided to save power, which is governed through programmed feedback circuit based on dissolved oxygen (DO) levels maintained in the bulk aeration reactor. Aeration is carried out through retrievable type membrane diffusers, placed at the floor level, spanning the entire floor area for uniform distribution of air. Man-Machine Interface is provided through a PLC System, which controls all operations except those on the Gates, some valves and the F/M ratio. The STP including sludge handling units has worked to its full designed capacity right since its commissioning. The secondary effluent is discharged in the nearby drain, the Amani Shah Nallah without any disinfection; it is tapped for irrigation by downstream farmers due to shortage of irrigation water as also for its rich Nitrogen Phosphorous Potassium (NPK) content. Unfortunately, many of these crops/vegetables sown /grown with this treated sewage are eaten, the consumption of which has been implicated as the cause of endemicity of amoebiasis in the city. The key parameters used for design of the STP are summarized in Table 3.1.

Table 3.1 Design influent parameters and effluent parameters of STP Delawas (Requirements of STP Delawas RUIDP, Jaipur, 2003)

Parameters	Raw sewage designed parameter	Treated sewage designed parameter	Parameters of treated wastewater (during study 2010 to 2013)
BOD_5	Up to 300 mg/L	30 mg/L or less	18-30 mg/L
COD	Up to 700 mg/L	250 mg/L or less	160-230 mg/L
Suspended solids	Up to 600 mg/L	100 mg/L or less	40-95 mg/L
pH	7.2 to 7.9	6 to 9	7.2-7.9

Parameters	Raw sewage designed parameter	Treated sewage designed parameter	Parameters of treated wastewater (during study 2010 to 2013)
Ammonnical Nitrogen	Up to 35 mg/L	No treatment; if required space available.	-
Total Nitrogen	Up to 55 mg/L	-do-	-
Total Phosphates	Up to 16 mg/L	-do-	-
TDS	Up to 1500 mg/L	No treatment	-

3.3. Influent and effluent parameters

Influent and effluent parameters, mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS) and unit wise power consumption are not properly maintained by most of the operators. In this study, operator was requested through the client to maintain record and routine data on daily basis for analysis of the functional performance of the units. Properly recorded data are useful to search out some new approaches to increase the functional performance and enhancement in the power generation in the existing power generation unit. It provides scope for reduction in power consumption with minor alternation in the Plant. Operator and client understood the approach and regularly maintained the routine data which were used for performance analysis and the study that was used to improve the PST performance.

The routine data record for the period of January 2010 to April 2012 for composite samples (sample drawn at every 2 h interval and composited on daily basis) were obtained from the operator's STP laboratory and were used for analysis of the plant performance in the present study. These daily data were used to derive the monthly average and standard deviation values of biological parameters being summarized in Table 3.2.

Table 3.2 Monthly average characteristics of raw and treated sewage and their standard deviation

S.No.	Month	Q (MLD)	Monthly average parameters(Influent)				Monthly average parameters (effluent)			
			BOD_5, mg/L	COD, mg/L	TSS, mg/L	pH	BOD_5 mg/L	COD, mg/L	TSS, mg/L	pH
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	January-2010	62.00	289	561	783	7.43	23	122	38	7.67
2	February-2010	61.9	290	572	785	7.42	22	124	41	7.61
3	March-2010	62.22	297	544	797	7.38	21	120	35	7.79
4	April-1020	60.57	297	797	546	7.38	21	120	36	7.789
5	May-2010	62.05	295	796	544	7.4	21	123	37	8.05
6	June-2010	62.19	295	789	529	7.4	21	116	34	7.55
7	July-2010	62.18	295	799	513	7.39	21	120	34	7.79
8	August-2010	62.24	296	801	521	7.56	20	121	34	7.87
9	September-2010	62.13	292	764	501	7.58	20.3	123	34	7.81
10	October-2010	61.95	287	762	500	7.56	21	116	35	7.8
11	November-2010	62.04	285	746	502	7.53	21	117	35	7.78
12	December-2010	61.95	288	725	510	7.53	20	118	37	7.82
13	January-2011	61.36	292	724	525	7.53	20	121	36	7.81
14	February-2011	61.92	291	727	559	7.52	21	123	39	7.79
15	March-2011	61.87	291	724	577	7.53	19	118	37	7.77
16	April-2011	61.91	291	719	567	7.53	20	119	39	7.72

S.No.	Month	Q (MLD)	Monthly average parameters(Influent)				Monthly average parameters (effluent)			
			BOD_5, mg/L	COD, mg/L	TSS, mg/L	pH	BOD_5 mg/L	COD, mg/L	TSS, mg/L	pH
17	May-2011	61.92	291	724	572	7.54	21	122	40	7.7
18	June-2011	61.88	289	712	550	7.54	21	120	40	7.69
19	July-2011	62.00	271	712	526	7.54	22	126	40	7.72
20	August-2011	61.9	276	721	533	7.54	27	151	48	7.73
21	Sept-2011	61.89	282	722	554	7.54	22	123	40	7.72
22	October-2011	61.91	284	716	570	7.54	22	124	40	7.72
23	November-2011	61.98	286	717	567	7.53	22	124	41	7.71
24	December-2011	61.91	279	717	559	7.53	23	126	41	7.72
25	January-2012	61.35	284	564	750	7.53	23	123	42	7.71
26	February-2012	61.86	277	564	744	7.53	22	125	41	7.72
27	March-2012	61.86	294	564	750	7.53	23	129	41	7.71
28	April-2012	62.08	287	565	768	7.53	23	130	42	7.72
Average for 28 months, and standard deviations		**61.89 (0.33)**	**288 (6.66)**	**698 (85)**	**596 (104)**	**7.50 (0.06)**	**22 (1.5)**	**119 (6.50)**	**41 (3.31)**	**7.75 (.09)**

The overall efficiency of STP in terms of BOD removal was about 92%, which showed satisfactory biological performance.

At the times colored wastewater was also seen at the inlet of the STP. The characteristics of colored waste entering the STP were monitored during study period. The source of color waste was the small house level dyeing units waste connected to sewer network in Sanganer area. The raw sewage characteristics when colored waste was observed at the inlet of STP were segregated during study period and summarized in Table 3.3.

Table 3.3 Measured characteristics of sewage showing color at the inlet of STP

Date	Time	Color	pH	TSS, mg/L	COD, mg/L
4.01.2012	3:55 PM	pink	7.48	736	1208
11.01.2012	4:05 PM	green	7.50	744	1240
17.01.2012	5:55 PM	pink	7.47	728	1192
27.01.2012	5:45 PM	milky	7.51	696	1112
29.01.2012	6:35 PM	green	7.49	718	1104
12.02.2012	6:50 PM	pink	7.46	764	1432
15.02.2012	5:25 PM	green	7.31	746	1488
19.02.2012	6:10 PM	green	7.37	736	1568
26.02.2012	5:35 PM	pink	7.48	694	1268
2.03.2012	4:10 PM	pink	7.33	760	1480
8.03.2012	3:50 PM	pink	7.39	748	1456
20.03.2012	6:10 PM	green	7.43	732	1424
24.03.2012	5:50 PM	pink	734	740	1416
31.03.2012	6:00 PM	green	7.43	810	1648
1.04.2012	9:50 AM	milky	7.29	696	1392
6.04.2012	5:50 PM	pink	7.16	646	1416
15.04.2012	12:30 PM	green	7.24	704	1520
26.04.2012	9:30 PM	pink	7.16	646	1432
4.05.2012	10:30 AM	pink	7.14	698	1352
11.05.2012	4:45 PM	pink	7.39	724	1504
15.05.2012	1:55 PM	green	7.19	708	1464
21.05.2012	9:30 PM	pink	7.31	658	1360
7.06.2012	5:10 PM	pink	7.26	692	1400

Date	Time	Color	pH	TSS, mg/L	COD, mg/L
11.06.2012	6:25 PM	green	7.30	712	1512
17.06.2012	5:45 PM	pink	7.32	676	1208
23.06.2012	11:10 AM	milky	7.23	652	1328

The values of TSS and COD were observed to be more than the designed values of 600 mg/L and 700 mg/L respectively. The COD/ BOD_5 ratio of the raw sewage was 2.42, which is higher than that for normal conditions (Metcalf and Eddy, 2003) indicating ingress of dye wastewater.

As per above derived monthly parameters, the plant has been functioning satisfactorily in terms of measured biological parameters except when colored wastewater from nearby printing textile Industries of Sanganer was received. The BOD to COD ratio changes due to dyes, which also affects the oxidation process. This STP is functioning to its full designed capacity since commissioning in September 2006. It's because, the sewer system in southern part of Jaipur along with trunk sewer was laid during the period of 1990 to 2000 prior to installation of STP.

3.4. Performance of aeration tank

To analyze the performance of aeration unit (secondary treatment) the data of biological parameters were collected and monthly average values of these with standard deviation were derived for the period of January 2010 to April 2012 and are summarized in Table 3.4.

Table 3.4 Derived monthly average values for influent and effluent of secondary level process

Influent & effluent values of secondary level process				Monthly average MLVSS in aeration tank, mg/L	Monthly average MLVSS in excess sludge, mg/L
S. No.	Month	Influent BOD (S_0), mg/L	effluent BOD (S), mg/L		
1.	Jan 2010	148.7	23	2028	8122
2.	Feb 2010	152.4	22	2118	8213
3.	March 2010	158.0	21	2131	8108
4.	April 2010	157.7	21	2118	8174
5.	May 2010	151.8	21	2128	8448
6.	June 2010	154.8	21	2121	8159
7.	July 2010	156.5	21	2108	8148
8.	Aug 2010	153.4	20	2111	8152
9.	Sept 2010	151.2	20	2110	8118
10.	Oct 2010	149.5	21	2115	8151
11.	Nov 2010	150.4	21	2107	8176
12.	Dec 2010	151.1	20	2142	8202
13.	Jan 2011	152.1	20	2055	8185
14.	Feb 2011	154.9	21	2130	7957
15.	Mar 2011	151.0	19	2122	8163
16.	April 2011	154.2	20	2098	8166
17.	May 2011	154.8	21	2101	8177
18.	June 2011	154.7	21	2105	8177
19.	July 2011	148.6	22	2096	8157
20.	Aug 2011	153.2	27	1706	8633
21.	Sept 2011	151.7	22	2062	8154
22.	Oct 2011	152.9	22	2114	7934
23.	Nov 2011	154.1	22	2144	8192
24.	Dec 2011	151.7	23	2128	8175

Influent & effluent values of secondary level process				Monthly average MLVSS in aeration tank, mg/L	Monthly average MLVSS in excess sludge, mg/L
S. No.	Month	Influent BOD (S_0), mg/L	effluent BOD (S), mg/L		
25.	Jan 2012	155.4	23	2708	8162
26.	Feb 2012	153.2	22	2687	8169
27.	Mar 2012	154.9	23	2717	8191
28.	April 2012	154.6	23	2725	8178
Average for 28 months, and standard deviation		153.13 (2.44)	22 (1.53)	2180 (234)	8176 (122.7)

The efficiency in terms of BOD removal of the aeration unit was about 85% indicating its satisfactory performance.

To assess the performance in terms of kinetic values i.e., θ_c, F/M Ratio and specific growth rate, monitored values of biological parameters were derived from the daily records of STP from January-2010 to December-2011, which are summarized in Table 3.5.

The operating parameters indicate that the F/M ratio was in the range of 0.33 to 0.44, while θ_c varied between 6.60 to 12.95 days. These values were different from the design values of 0.30 and 8 days respectively, despite the fact that the influent characteristics were in tune with the designed parameters. To identify the reasons for above deviations, hydraulic flow parameters were analyzed and it was found that the actual retention time in aeration tank was only 4 h instead of its design value of 6 h. This was due to a very high return sludge flow rate of 31.25 MLD, which is about 50% of average raw sewage flow entering the STP for treatment. It was inferred that such a high flow rate is not permitting proper settling of the secondary sludge. Also during the lean inflow sewage hours, as the return sludge flow rate has been kept constant, practically the complete treated sewage is sent to the aeration tank through recycle line. Thus, there is a need to modify and control the return sludge flow rate as per demand either by putting variable frequency driven return sludge pumps or operating the return line through multiple pumps operated in a sequence to match the hydraulics of inflow of sewage.

Table 3.5 Estimation of specific solids growth rate and Sludge age (θ_c) values of aerobic oxidation at STP Delawas Jaipur

Observed data								Solid produced (X_t), (g/day)	(F/M Ratio)	Specific solid growth rate (per day)	Sludge age (θ_c), days
S. N.	Month	Influent flow rate (Q), L/day	influent BOD_5 (S_0), mg/L	effluent BOD_5 (S), mg/L	Time, h	MLVSS					
						mg/ L	g				
1	2	3	4	5	6	7	8	9	10	11	12
							(col 3x col 7)/ 1000x (col 6)/24	Sludge drawn from sec. clarifier	(col.4-col 5)x col.3/ (col 8x1000)	(Col 9/ col 8)	(col 8/ col 9)
1	Jan- 2010	62005484	148.74	22.52	4.03	2028	21115037	2399192	0.37	0.11	8.8
2	Feb- 2010	61910000	152.3	21.86	4.03	2118	22018137	2786955	0.37	0.13	7.9
3	Mar- 2010	62223871	158.0	21.26	4.02	2131	22210344	2866072	0.38	0.13	7.77
4	Apr- 2010	60573333	157.7	20.67	4.09	2118	21863490	2802104	0.39	0.13	7.69
5	May- 2010	62050000	151.7	20.45	4.03	2128	22172120	3330653	0.37	0.15	6.66
6	Jun- 2010	62194333	154.8	20.9	4.02	2121	22095625	2662554	0.38	0.12	8.32
7	Jul -2010	62183871	156.4	21.13	4.02	2108	21956503	1888834	0.38	0.09	11.66
8	Aug -2010	62239355	153.4	20.35	4.02	2111	22007369	2360934	0.38	0.11	9.34
9	Sep- 2010	62129000	151.2	20.3	4.02	2110	21957942	2937573	0.37	0.13	7.49
10	Oct- 2010	61955806	149.4	20.84	4.03	2115	22003217	2828011	0.36	0.13	7.78
11	Nov- 2010	62041333	150.4	20.63	4.03	2107	21950249	2896175	0.37	0.13	7.58
12	Dec -2010	61950968	151.1	20.16	4.03	2142	22282369	2832578	0.36	0.13	7.87
13	Jan -2011	61356452	152.1	20.35	4.06	2055	21329804	2868503	0.38	0.13	7.43

Observed data								Solid produced (X_t), (g/day)	(F/M Ratio)	Specific solid growth rate (per day)	Sludge age (θ_c), days
S. N.	Month	Influent flow rate (Q), L/day	influent BOD_5 (S_0), mg/L	effluent BOD_5 (S), mg/L	Time, h	MLVSS					
						mg/ L	g				
1	2	3	4	5	6	7	8	9	10	11	12
							(col 3x col 7)/ 1000x (col 6)/24	Sludge drawn from sec. clarifier	(col.4-col 5)x col.3/ (col 8x1000)	(Col 9/ col 8)	(col 8/ col 9)
14	Feb- 2011	61927857	154.9	21.79	4.03	2130	22149272	2962331	0.37	0.13	7.53
15	Mar- 2011	61866774	150.9	19.6	4.04	2122	22099018	2860816	0.37	0.13	7.76
16	Apr- 2011	61914333	154.1	20.2	4.03	2098	21811749	2716667	0.38	0.12	8.09
17	May- 2011	61924516	154.7	21.3	4.03	2101	21846531	2848851	0.38	0.13	7.72
18	Jun- 2011	61883333	154.6	21.1	4.04	2105	21927843	2920279	0.38	0.13	7.54
19	Jul- 2011	62002258	148.6	22.4	4.03	2096	21821901	3012684	0.36	0.14	7.29
20	Aug- 2011	61898710	153.2	27.0	4.03	1706	17731866	2142519	0.44	0.12	8.33
21	Sep- 2011	61889000	151.6	22.1	4.04	2062	21481878	3032620	0.37	0.14	7.12
22	Oct- 2011	61911935	152.8	21.9	4.03	2114	21977241	3087487	0.37	0.14	7.17
23	Nov- 2011	61981000	154.0	22.3	4.03	2144	22313986	3107309	0.36	0.14	7.23
24	Dec- 2011	61911613	151.6	22.7	4.03	2128	22122670	1720374	0.36	0.08	12.95
Average values		61913547	152.84	21.41	4.03	2091	21760256	2744669	0.38	0.13	8.13
Standard Deviations		334312	2.54	1.47	0.01	86.40	903335	383239	0.02	0.02	1.42

It was observed that the dissolved oxygen (DO) level maintained in the aeration tank was only 0.5 mg/L, which was much lower than the recommended range of 1.0-3.0 mg/L (Metcalf and Eddy, 2007) for conventional ASP. This action was probably taken for extra savings in power, but it resulted in prevalence of anaerobic conditions within the flocs as exemplified by consequent reduction in pH. It further resulted in higher survival of coliforms and pathogens as they are primarily originating from intestines, which are under anaerobic conditions. The detailed microbiological analysis indicated that the average total and pathogenic counts of raw, primary and secondary treated sewage were $4x10^8$ & 5.4×10^7 ; 8×10^6 & 6.2×10^6 ; and 1.6×10^6 & 7.6×10^6 per 100 mL respectively (Pancholi, 2009). The above values exceed the norm of $<10^5$ bacteria/100 mL recommended for restricted irrigation (Ursula et al., 2000). The reported pathogenic count, may have far more negative consequences on environment than the benefits of power saving. It may further increase the cost of tertiary treatment (disinfection), if required in future to meet the reuse (if any) norms.

3.5. Operation and Maintenance Cost

Operation and Maintenance of STP for 5 years from the date of commissioning was with the same agency, which has constructed the STP,. The process power guaranteed consumption of 8576 kWh/day was given by the operator during the O&M period of 5 years at the time of bidding and this power consumption was capitalized and considered in the evaluation of cost at the time of award of the contract.

Average annual O&M costs were also derived with the available data, which included the cost of manpower, wear and tear of machinery, chemicals and maintenance of plantation. O&M expenditure derived from the record of STP site for the period from 2006-07 to 2012 is summarized in Table 3.6:

Table 3.6 Operation and Maintenance Cost of STP (M/s VA TECH WABAG., Jaipur STP Delawas, 2013)

O & M Charges of 62.50 MLD STP (year-wise)	Cost per month (Rs. in lacs)		
	Average Power charges paid / month	Average O&M cost paid / month	Average total monthly paid O&M Cost
I year (operation started in Sept-2006 (2006-07)	13.6	2.66	16.26
II year (2007-08)	14.10	2.82	17.07
III year (2008-09)	14.90	2.98	18.23
IV year (2009-10)	15.75	3.16	19.91
V year (2010-11)	4.16*	3.36	7.52
VI year (2011-12)	6.45**	3.36	9.81

* Power generation through bio gas produced at STP installed in year 2009 and fully put in to operation from February-2010 was used for operation of STP; power from grid was taken during peak flow demand.

** Power charges increased in year 2011-12 due to less power generation; more power from grid was taken.

The calculated operating costs for treatment of 62.50 MLD in years 2006-07 to 2009-10 were Rs. 26016, Rs.27312, Rs. 29168 and Rs.329168 per MLD respectively. This cost is on lower side of Rs. 30000 per MLD reported by CPCB, India, 2013. In STPs, energy cost for treatment of each MLD of sewage constitutes 65-75% of the total O&M cost depending on the process used (ASP/MBBR/MBR). This indicates that there is a high variability in unit power consumption and scope exists for its optimization (Arceivala and Asolekar, 2007).

3.6. Power consumption in operation of STP

Sewage treatment is a significant user of energy. Operation of pumps, blowers and other equipment at a typical sewage treatment plant requires annual electrical energy consumption in the range of 12-15 kWh per person-year (considering 80% of water @180 L per capita per day is contributing to sewage reaching to STP for treatment. The energy consumption was derived from the actual data taken from operation and maintenance record of STP. Based on daily consumption records, the monthly consumption was derived from November 2006 to 2009 and is summarized in Table 3.7.

Table 3.7 Summary of monthly power consumed at Delawas STP derived from plant operation data (M/s Va Tech Wabag Jaipur, 2013)

S. No.	Month	year	Guaranteed power consumption (kWh)	Actual power consumption (kWh)
1	November-2006		257280	230372
2	December-2006		257280	211536
3	January-2007	2007	257280	207861
4	February-2007	2007	257280	205322
5	March-2007	2007	257280	170666
6	April-2007	2007	257280	194323
7	May-2007	2007	257280	226491
8	June-2007	2007	257280	227524
9	July-2007	2007	257280	222209
10	August-2007	2007	257280	230729
11	September-2007	2007	257280	203318
12	October-2007	2007	257280	199095
13	November-2007	2007	257280	210974
14	December-2007	2007	257280	212636

S. No.	Month	year	Guaranteed power consumption (kWh)	Actual power consumption (kWh)
15	January-2008	2008	257280	222190
16	February-2008	2008	257280	394742
17	March-2008	2008	257280	208882
18	April-2008	2008	257280	231429
19	May-2008	2008	257280	225623
20	June-2008	2008	257280	211230
21	July-2008	2008	257280	186117
22	August-2008	2008	257280	170326
23	September-2008	2008	257280	186852
24	October-2008	2008	257280	173048
25	November-2008	2008	257280	180507
26	December-2008	2008	257280	210534
27	January-2009	2009	257280	235902
28	February-2009	2009	257280	238482
29	March-2009	2009	257280	212458
30	April-2009	2009	257280	236842
31	May-2009	2009	257280	194720
32	June-2009	2009	257280	215590
33	July-2009	2009	257280	219300
34	August-2009	2009	257280	222688
35	September-2009	2009	257280	166164
36	October-2009	2009	257280	92027
37	November-2009	2009	257280	131458
Average of above and standard deviation			**257280 (0)**	**208653 (43502)**

Table 3.7 shows that during the period from year 2006 to 2009, the average power consumed was 208653 kWh/month against the allowed power consumption up to 257280 kWh/ month. A deviation of 43502 kWh/month in power consumption for operation of plant was observed during the data analysis. This deviation could be attributed to power failure and/ or equipment failure/maintenance.

3.7. Unit wise power consumption

Unit wise power consumption was also derived based on operating installed load, running hours and efficiency of the motor as per the record of operating agency as listed in Table 3.8:

Table 3.8 Unit wise power consumption derived on the basis of operating installed load (Documents of M/s Vatech Wabag, 2013)

S.No.	Unit	No of units in function	Motor load rating (kW)	Running hrs.	Full load motor efficiency	Power consumption (kW/day)
1	**2**	**3**	**4**	**5**	**6**	**7** **Col.5X col.4 X col.3**
I.	Coarse screen	1	1.1	3	78	2.57
II.	Belt conveyor of coarse screen	1	1.5	3	8%	0.36
III.	Raw sewage pump	4	45	24 h for 2 pumps (for calculation purpose)	93%	2009
IV.	Fine screen	1	3.7	10	84%	31.08
V.	Belt conveyor of fine screen	1	1.5	10	8%	1.20
VI.	Grit separator	2	0.75	24	77%	27.72
VII.	Screw classifier	2	1.12	24	78%	41.93
VIII.	Organic return pump	2	0.37	24	77%	13.68

S.No.	Unit	No of units in function	Motor load rating (kW)	Running hrs.	Full load motor efficiency	Power consumption (kW/day)
1	**2**	**3**	**4**	**5**	**6**	**7 Col.5X col.4 X col.3**
IX.	Primary clarifier	2	0.75	24	73%	26.28
X.	Primary sludge pump	2	3.7	20	85%	125.80
XI.	Air blower	4	75	24h (2 blower)+ 12 h for 2 blower	94%	5076.00
XII.	Secondary clarifier	2	1.5	24	8%	5.76
XIII.	High pressure pump	2	7.5	12	85%	153.00
XIV.	Return sludge pump	1	22	24	89%	469.92
XV.	Primary sludge thickener	1	0.75	24	73%	13.14
XVI.	Digester feed pump	1	5.5	12	86%	56.76
XVII.	Thickened sludge Sump agitator	1	3.7	5	84%	15.54
XVIII.	Digester mixing pump	4	9.3	6	88%	196.42
XIX.	Sludge balancing tank agitator	1	3.7	6	84%	18.65
XX.	Centrifuge feed pump	2	2.2	12	82%	43.30
XXI.	Centrifuge	2	18.5	12	9%	39.96
XXII.	DWPE dosing tank agitator	2	0.75	12	77%	13.86
XXIII.	DWPE dosing pump	2	0.37	12	77%	6.84
XXIV.	Excess sludge	1	1.5	6	76%	6.84

S.No.	Unit	No of units in function	Motor load rating (kW)	Running hrs.	Full load motor efficiency	Power consumption (kW/day)
1	**2**	**3**	**4**	**5**	**6**	**7 Col.5X col.4 X col.3**
	feed pump					
XXV.	Poly electrolyte agitator2 nos.	2	0.37	6	77%	3.42
XXVI.	Poly electrolyte dosing pump	1	0.37	6	77%	1.71
XXVII.	Excess sludge thickener	1	0.75	6	77%	3.47
XXVIII.	Wash water feed pump	1	2.2	2	82%	3.61
XXIX.	Motorized valve	4	0.37	6	77%	6.84

Based on Table 3.8 details of unit wise calculated power required is summarized in Table 3.9.

Table 3.9 Unit wise calculated (required) power

S.No.	Units	Calculated power requirement, (kWh)	Power requirement of total, %
1	Screening	35	0.42%
2	Raw sewage pump	2009	23.88%
3	Grit separator	95	1.13%
4	Primary clarifier	152	1.81%
5	Aeration tank	5076	60.33%
6	Secondary clarifier	134	1.59%
7	Sludge handling	913	10.85%
Total		8414	100.00%

In this study it was revealed that major unit wise calculated power consumption in aeration was 60.33% of the total. This is lower than the designed value of about 75 %. Lower power consumption in aeration also indicates, that perhaps the performance of STP is not satisfactory in biological terms due to low DO being maintained in the aeration unit, which was further confirmed by an increase in the coliform count (Pancholi, 2009).

3.8. Power drawn from grid

Similarly, data for power taken from grid after installation of power generation unit were derived from daily records and summarized in Table 3.10.

Table 3.10 Power drawn from grid after installation of power generation unit from December 2009 to April 2012

S.No.	Month	Year	Total power consumption (kWh)	Power supply taken from grid (kWh)
1.	December	2009	324313	97276
2.	January	2010	332143	63216
3.	February	2010	312032	45213
4.	March	2010	319075	48960
5.	April	2010	208224	55739
6.	May	2010	215689	92323
7.	June	2010	235454	50216
8.	July	2010	221283	68800
9.	August	2010	236285	57740
10.	September	2010	214602	51215
11.	October	2010	230256	50562
12.	November	2010	232916	29246
13.	December	2010	192593	78205

S.No.	Month	Year	Total power consumption (kWh)	Power supply taken from grid (kWh)
14.	January	2011	159439	112413
15.	February	2011	147892	106198
16.	March	2011	172620	57360
17.	April	2011	199204	14584
18.	May	2011	184851	33592
19.	June	2011	193541	9813
20.	July	2011	182826	43221
21.	August	2011	189744	79409
22.	September	2011	149345	66224
23.	October	2011	170810	78322
24.	November	2011	133183	35403
25.	December	2011	152328	32922
26.	January	2011	155844	37642
27.	February	2012	143661	38508
28.	March	2012	180054	40070
29.	April	2012	164098	34520
Monthly Average from December 2009 to April 2012 and standard deviation			**205320 (55800)**	**55480 (25620)**

Table 3.10 revealed that during the period from 2009 to 2012, the average power consumed was 205320 kWh/month. The average power supply derived from grid was only 55480 kWh/ month for the period from December 2009 to April 2012, which constituted only 27% of the total average monthly consumption.

3.9. Power generation unit of STP

Primary and secondary excess sludge is processed in anaerobic digesters. Digested sludge is pumped to a centrifuge unit where it is converted to semi solid form and used as manure. To utilize the gases produced during anaerobic digestion of sludge in digesters, a power generation unit based on biogas produced has been installed. Energy saving measures have been taken for the plant operations that have resulted in substantial savings in the energy costs.

A substantial input of energy is required to treat sewage from densely populated areas and sewage treatment often comprises the largest use of electricity by local governments. Conventional STPs remove organic content from the wastewater stream by reacting the proteins, fats and carbohydrates with oxygen from air. This oxidation process is undertaken at ambient temperature by the enzymes secreted by aerobic bacteria that convert most of the organic material to carbon dioxide and water through dissimilatory processes. The process also produces sewage sludge, or bio-solids, consisting of un-oxidized organic matter and predominantly bacterial cells. Some treatment plants further reduce the quantity of bio-solids through an anaerobic treatment process. Here, in the absence of air, anaerobic bacteria digest the bio-solids, producing "biogas", a mixture of methane and carbon dioxide. Methane is the main component of the biogas produced and can be burnt in an engine or turbine to produce power and generate electricity. In this way, anaerobic treatment can generate electrical energy used in the sewage treatment plant. Fig 3.3 shows the overview of Digester unit of STP, Delawas.

Figure 3.3 Overview of Digester units

At STP Delawas, the power required for operation is being supplied from two sources; first, from power grid and the second, from the biogas based power plant of 1.0 MW (0.50 MW standby) capacity working since year 2008. To get the composition of gases produced in anaerobic digestion, gas samples were tested through the operating agency the results of which are summarized in Table 3.11.

Table 3.11 Characteristics of biogas produced during sludge digestion (M/s Va tech Wabag, 2013)

<table>
<tr><td colspan="5">Sludge generation</td><td>55-60 m³/day</td></tr>
<tr><td colspan="5">Gas generated during anaerobic digestion</td><td>5800-6200 Nm³/ day</td></tr>
<tr><td>The Characteristic & calorific value of produced gases</td><td>Methane (CH₄) %v/v</td><td>CO₂ %v/v</td><td>H₂S %v/v</td><td>Calorific value kCal/m³</td><td rowspan="5">Tested at Laboratory of Shriram Institute, New Delhi</td></tr>
<tr><td>Morning sample 1</td><td>52.2</td><td>35.00</td><td>1.02</td><td>5025</td></tr>
<tr><td>Mid-day sample 2</td><td>57.5</td><td>30.00</td><td>1.26</td><td>5613</td></tr>
<tr><td>After noon sample 3</td><td>54.8</td><td>35.00</td><td>1.07</td><td>5279</td></tr>
<tr><td>Protocol/ method followed</td><td>GC-FID</td><td>Orsat Apparatus</td><td>IS-11255</td><td>IS-14504</td></tr>
</table>

Cost viability calculations were also made, which are shown in Table 3.12. The per kWh cost of electricity was considered as Rs.6.30 for 1st year & Rs. 6.90, Rs 7.6, Rs. 8.30, Rs 9.20, Rs. 10.10, Rs.11.10, Rs. 12.20, Rs. 13.40, Rs.14.70 for subsequent years up to 10 years period for calculation purposes as summarized in Table 3.12.

Table 3.12 Cost viability calculations for power generation unit

							Cost, Rs. in Lacs.
Year	**Project execution cost**	**O&M cost /year**	**Cumulative cost /year**	**Cumulative interest (@ 15% per year)**	**Total Exp./ year**	**Cost of power to be generated /year**	**Saving/ year**
1	2	3	4	5	6=(4+5)	7	8=(6-7)
2008	750.00	30.00	780.00	117.00	897.00	216.71	-680.28
2009	0	30.00	810.00	238.50	1048.50	476.78	-571.71
2010	0	36.00	846.00	365.40	1211.40	786.68	-424.71
2011	0	42.00	888.00	498.60	1386.60	1153.81	-232.78
2012	0	42.00	930.00	638.10	1568.10	1586.48	18.38
2013	0	48.00	978.00	784.80	1762.80	2094.16	331.36
2014	0	48.00	1026.00	938.70	1964.70	2687.51	722.81
2015	0	54.00	1080.00	1100.70	2180.70	3378.58	1197.88
2016	0	54.00	1134.00	1270.80	2404.80	4181.00	1776.20
2017	0	66.00	1200.00	1450.80	2650.80	5110.11	2459.31

As per Table 3.12 the capital expenditure can be paid back along with compound interest (@ 15%) in 5 years (2012). Thus, in remaining 5 years (out of ten years O&M period) plant will generate power with an equivalent cost of about Rs. 24.59 crores (cumulative amount); which can be utilized for other works.

Details of power generation from the gases produced in anaerobic digesters is shown in Table 3.13.

Table 3.13 Details of bio gas generated from the digester

Particulars	Value
Amount of gas generated from 62.5 MLD Plant	Average about 6000 m^3/day or 250 m^3/h
Calorific value of gas	5000 to 5600 kCal /m^3
Total heat energy of gas	1300000 kCal/h
Total energy in kW hour	1509.3
Efficiency of power Generation unit engine and generator	28 %
Electrical energy generation potential	400 kWh (9600 unit/day)

The monthly power generation from biogas was calculated based on daily available data from Dec-2009 (when power generation unit was put in to operation) to April-2012 and summarized in Table 3.14.

Table 3.14 Monthly power generated from biogas

S. No.	Month	Year	Power generated/month, kWh
1	December	2009	227037
2	January	2010	268927
3	February	2010	266819
4	March	2010	270115
5	April	2010	152485
6	May	2010	123366
7	June	2010	185238
8	July	2010	152483
9	August	2010	178545
10	September	2010	163387

S. No.	Month	Year	Power generated/month, kWh
11	October	2010	179694
12	November	2010	203670
13	December	2010	114388
14	January	2011	47026
15	February	2011	41694
16	March	2011	115260
17	April	2011	184620
18	May	2011	151259
19	June	2011	183728
20	July	2011	139605
21	August	2011	110335
22	September	2011	83121
23	October	2011	92488
24	November	2011	97780
25	December	2011	119406
26	January	2011	118202
27	February	2012	105153
28	March	2012	139984
29	April	2012	129578

The monthly average guaranteed power requirement to operate the plant as per design was 257280 kWh/month while the average power produced at the initial month of December-2009 was 227037 kWh/month constituting about 88 % of the average consumption. The average production of power in years 2010 and 2011 was 188260 and 113860, kWh/ month respectively, which covered 73% and 44% of total consumption indicating decline in the efficiency of the digesters. The average production during January-2012 to April-2012 was 123230 kWh/month showing marginal improvement making an overall average of 58% coverage of the consumption by production through digesters for the period of December-2009 to April-2012. It showed that though it is feasible to meet 88% of the power consumption through digester gases, these units need to be properly operated. Figure 3.4 and Figure 3.5 shows the view of Gas engine and gas holders installed at power generation unit in the premises of STP.

Figure 3.4 Biogas based power generation unit of STP Delawas Jaipur

Figure 3.5 Gas holder and power generator room of STP Delawas Jaipur

The monthly average power consumption before and after power generation through digesters at STP, Delawas is summarized in Table 3.15

Table 3.15 Power consumption before and after installation of power generation unit

S. No.	Month/ year	Total monthly power consumed, kWh	Monthly power generated, kWh	Monthly power drawn from Grid, kWh	Monthly power saving, kWh
1	Dec-2009	324313	227037	97276	227037
2	Jan-2010	332143	268927	63216	268927
3	Feb-2010	312032	266819	45213	266819
4	Mar-2010	319075	270115	48960	270115
5	April-2010	208224	152485	55739	152485
6	May-2010	215689	123366	92323	123366
7	June-2010	235454	185238	50216	185238
8	July-2010	221283	152483	68800	152483

S. No.	Month/ year	Total monthly power consumed, kWh	Monthly power generated, kWh	Monthly power drawn from Grid, kWh	Monthly power saving, kWh
9	Aug-2010	236285	178545	57740	178545
10	Sept-2010	214602	163387	51215	163387
11	Oct-2010	230256	179694	50562	179694
12	Nov-2010	232916	203670	29246	203670
13	Dec-2010	192593	114388	78205	114388
14	Jan-2011	159439	47026	112413	47026
15	Feb-2011	147892	41694	106198	41694
16	Mar-2011	172620	115260	57360	115260
17	April-2011	199204	184620	14584	184620
18	May-2011	184851	151259	33592	151259
19	June-2011	193541	183728	9813	183728
20	July-2011	182826	139605	43221	139605
21	Aug-2011	189744	110335	79409	110335
22	Sept-2011	149345	83121	66224	83121
23	Oct-2011	170810	92488	78322	92488
24	Nov-2011	133183	97780	35403	97780
25	Dec-2011	152328	119406	32922	119406
26	Jan-2011	155844	118202	37642	118202
27	Feb-2012	143661	105153	38508	105153
28	Mar-2012	180054	139984	40070	139984
29	April-2012	164098	129578	34520	129578
Average, monthly		205320	149841	55479	149841

It may be observed from Table 3.15 that the average monthly power generated was 149841 kWh, which met 73% of the average daily consumption of the power required for operation of STP resulting in huge savings.

It is a common practice that the routine analysis of the raw and the final treated sewage is carried out in the laboratories of different STPs and the data are used only for the regulatory compliance purposes. Data are generally available these days due to automation that can be used to assess the performance of individual operations/processes, but are ignored for bringing out indicators to improve these units. Better/new diagnostic methods are required for close control over the process (Haimi et al., 2010). These days, due to extensive automation of the STPs, there is an availability of data uninterruptedly through Program Logistic Control (PLC), which can be used judiciously for improving its performance. A similar attempt was made for the improvement of PST by monitoring it over a long period to derive some clues in order to enhance the energy yield of the STP.

3.10. Primary settling tank performance

The monitored values of parameters like BOD_5, COD, TSS & pH of effluent entering the primary clarifiers and its effluent were derived from the available data at the STP, for which the analysis was carried out for the present research work and records were maintained in order to analyze its efficiency. The monthly average values of parameters derived based on field data are presented in Table 3.16

Table 3.16 Primary Clarifier inlet & outlet parameters

Period	Raw Sewage Treated (average daily)	Primary Clarifier inlet				Primary Clarifier outlet			
		BOD	COD	TSS	pH	BOD	COD	TSS	pH
	MLD	mg/L	mg/L	mg/L		mg/L	mg/L	mg/L	
March- 2010	62.94	328	883	602	8.17	175	357	243	8.39
April- 2010	61.29	297	797	546	7.38	158	325	220	7.58
May- 2010	62.77	295	796	545	7.40	152	317	217	7.58
June- 2010	62.91	295	789	529	7.40	155	314	215	7.56
July- 20100	62.90	295	799	513	7.39	156	313	216	7.57
Aug- 2010	62.96	296	801	521	7.56	153	318	218	7.72
Sept- 2010	62.85	292	764	501	7.58	151	314	212	7.60
Oct- 2010	62.68	287	762	500	7.56	149	309	207	7.62
Nov- 2010	62.76	285	746	502	7.53	150	310	206	7.58
Dec- 2010	62.67	288	725	510	7.53	151	310	208	7.57
Jan- 2011	62.62	292	724	526	7.53	152	318	213	7.60
Feb- 2011	62.65	291	727	559	7.52	155	322	219	7.59
March- 2011	62.59	291	724	578	7.53	151	318	219	7.58
Apr- 2011	62.63	291	719	567	7.53	154	321	222	7.31
May- 2011	62.64	291	724	572	7.54	155	320	222	7.32
June- 2011	62.60	289	712	550	7.54	155	318	220	7.49
July- 2011	62.72	271	712	526	7.54	149	315	213	7.56
Aug- 2011	62.62	276	721	533	7.54	153	318	167	7.57
Sept- 2011	62.61	282	722	554	7.54	152	322	222	7.56
Oct- 2011	62.63	284	716	570	7.54	153	319	220	7.56
Nov- 2011	62.70	286	717	567	7.53	154	322	220	7.56
Dec- 2011	62.63	279	717	559	7.53	152	320	218	7.55
Jan- 2012	62.61	284	725	562	7.54	155	324	218	7.57

Period	Raw Sewage Treated (average daily)	Primary Clarifier inlet				Primary Clarifier outlet			
		BOD	COD	TSS	pH	BOD	COD	TSS	pH
	MLD	mg/L	mg/L	mg/L		mg/L	mg/L	mg/L	
Feb 2012	62.58	277	744	564	7.53	153	331	218	7.59
March- 2012	62.59	294	750	564	7.53	155	330	219	7.57
April- 2012	62.80	287	768	565	7.53	155	441	219	7.57
May- 2012	62.82	288	792	559	7.53	157	353	219	7.57
Average	**62.66**	**289**	**750**	**546**	**7.54**	**154**	**325**	**215**	**7.59**

The results presented in Table 3.16 indicate that the PST has an average efficiency of 46%, 56 %, and 60% for the removal of $BOD_{5,}$ COD and TSS respectively. The BOD removal was more than the envisaged designed value of 40%. The observations of PST efficiency for organics and TSS removal and the energy calculation of the digesters including apportionment of contribution coming from primary and secondary sludges led to the design of a series of experiments for improving its efficiency; the results of which are described in the next chapter.

3.11. Contribution of the study presented in this chapter

The contribution of Chapter 3 lies in the development of a unique methodology for gaining insight in to the plant performance, providing diagnostics for the problems faced, and bring out the logic for the trial of a new strategy for return sludge to augment the performance of the STP through the following steps:

(i) The performance of individual units of the STP was got assessed, the data were recorded and critically analyzed for suspended solids and organics and for deriving kinetic values of the biological process, which led to troubleshooting as well as framing the augmentation strategy for the STP.

(ii) Monitoring and assessment of data on power consumption of individual units at the STP led to the logic that the DO levels in the aeration tank were too low as the unit power consumption was too low and the apportioned contribution of aeration tank(AT) to that of the total plant was also relatively low. The DO observations were thus checked and the values obtained (about 0.5 mg/L) were really found to be much lesser than the recommended range of 1.0-3.0 mg/L (Metcalf and Eddy, 2007). This observation was further strengthened by providing experimental support through the monitored values of pH and SVI and subsequently a detailed microbiological analysis was carried out to establish the diagnosis. This would have taken a long time if only the changes in pH and SVI were tracked.

(iii) The performance of PST in terms of TSS and BOD removal was the key to assess that its augmentation was possible by inducing some flocculent, which would not interfere with the biological process. A new strategy was framed for recycling a part of the return sludge to the PST rather than to the conventionally practiced aeration tank in order to augment the performance of the STP. Reports were available on conditioning of primary sludge through a brief aeration period as well as use of some excess sludge for enhancing flocculation, but in this study the application of conditioned excess sludge after thickening and aeration was tried, which yielded excellent results. Use of return sludge as a flocculent would improve settling in PST and at the same time does not have any detrimental effects of a chemical flocculent on biological process being carried out at secondary stage.

(iv) The hydraulic data of the plant indicated the faulty operation of the return sludge line, which resulted in much lesser HRT in the aeration tank thereby affecting its performance in terms of organics removal as well that of biomass settleability.

(v) In sum, diagnostics have been developed in the present study through a judicious handling of the aforementioned data for troubleshooting in the plant. The critical analysis of data pertaining to both process performance and energy consumption became the basis for the design of a series of experiments for enhancement of the energy yield by attempting improved settling in PST. This approach can help develop protocols for continuous assessment and diagnostics for troubleshooting at STPs and help optimize the process both in terms of organics removal as well as energy demand.

CHAPTER 4

PERFORMANCE ENHANCEMENT OF PST BY ADDITION OF BIOLOGICAL SLUDGES AS FLOCCULENT - EXPERIMENTAL STUDY

The chapter presents the experimental study on the use of excess sludge as a readily available, low cost, and risk-free flocculent, to enhance the performance of primary settling tank. It explains the experimental set-up fabricated and the detailed methodology followed. The results have been interpreted to suggest an optimum strategy for achieving favorable energy balance in the process.

The major energy fraction of biological sludges from STPs comes from the primary sludge, as it consists of more easily digestible carbohydrates and fats, compared to activated sludge, which consists of complex carbohydrates, proteins and long chain hydrocarbons (Zhang, 2010). Thus, not only that the biogas is more easily produced from primary sludge, its energy content compared to excess secondary sludge is also very high. Thus, wherever any energy generation unit based on anaerobic digestion of sludges exists in a STP, any extra removal of suspended organics from the primary clarifier can add greatly to the energy generation potential from the sludge. At the same time, an equivalent extra energy would be saved as these organics will not reach the aeration tank thereby not requiring oxidation. Chemical coagulants are generally discouraged from use in any STP as they may interfere with the biological processes of sewage as well as sludge treatment. The secondary sludge contains higher amounts of extracellular polymers, which possess excellent flocculation characteristics which can be used for enhancement of settling performance at primary treatment. Some studies have been reported on the use of sludges to improve the efficiency of primary settling tank. Use of polymers and experiments with primary sludge itself with brief aeration added to the PST have been carried out by some researchers (Yetis and Tarlan, 2002; Huang and Li, 2000). But limited work has been carried out in India on this aspect (CPCB, 2013). A series of experiments was carried out in the field laboratory of STP Delawas with the application of different secondary sludges, with and without conditioning to improve the performance of PST through controlled mixing with raw sewage. Digested sludges from anaerobic and aerobic sludge digesters of STP Delawas (Jaipur South) and STP Brahmapuri (Jaipur North) respectively were tried. The thickened secondary excess sludge from STP Delawas was then aerobically digested and process was repeated again with the municipal sewage entering to STP Delawas. The uniqueness of the study lies in the fact that no reports could be traced in the literature on the application of secondary return sludge with or without modifications as a flocculent to improve settling of primary sludge to produce power generation and save energy in operation of STPs. Thus, some part of the return sludge would be sent to the PST instead of AT requiring minimal changes in the treatment plant at almost no cost. The details of these experiments are described in the following sections.

4.1. Experimental set up and methodology for laboratory experiments

Controlled addition of different types of sludges in different volumes to the raw sewage was carried out in 1200 mL capacity imhoff(reactor) cone representing PST. These were made of glass having conical bottom as shown in Figure 4.1.

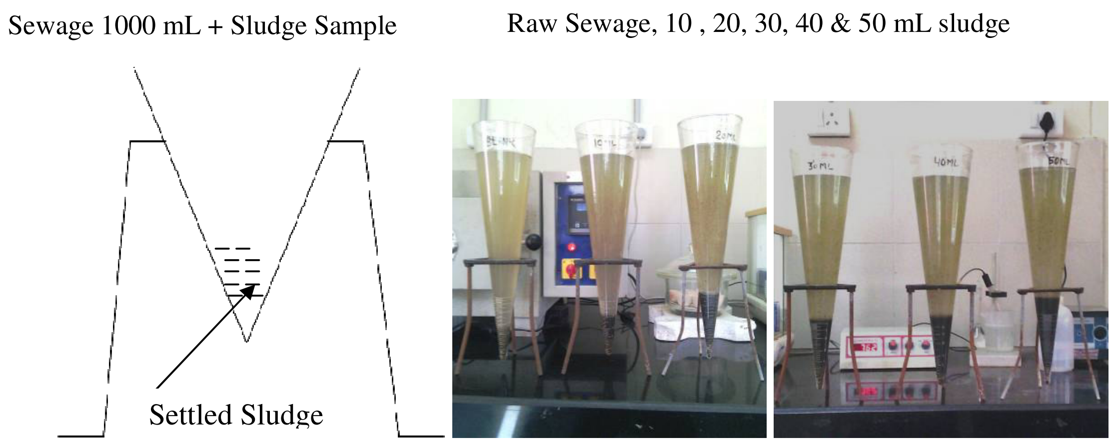


Figure 4.1 Experimental set up (Imhoff Cone)

Grab samples of sewage were used in study and were drawn as per the guidelines specified in manual on Water and Wastewater analysis issued by Central Pollution Control Board(CPCB), Ministry of Environment and Forest, New Delhi (1993). Samples of raw sewage of 20 L were collected from the inlet of the STP in plastic bottles and analyzed for the parameters, TSS, COD, BOD and filtered BOD as per the procedures laid down in above CPHEEO guidelines. Initially 1000 mL of raw sewage sample was filled in the imhoff cone and subjected to settling analysis. Settled samples were drawn from the top surface of the glass cone at regular intervals of 30 min for 2 h. The experimental set up was kept in the air-conditioned laboratory, where the temperature was maintained at about 27°C. All the samples were analyzed for TSS, COD, total BOD, and filtered BOD.

In the next stage of experiments, raw excess sludge was drawn from the secondary settling tank (SST) of STP Delawas and 10 mL, 20 mL 30 mL, 40 mL and 50 mL of it were added to 1000 mL of raw sewage in different sets of imhoff cones(reactor) for settling analysis. After addition of controlled volume of sludge in the raw sewage, the mixture was shaken simply by turning the covered vessel up and down three to four times and a sample was drawn to represent time zero. The mixture was then allowed to settle and after time intervals of every 30 min for the next 2 h, samples were drawn from the clear supernatant in the cylinder and analyzed for BOD_5, COD, TSS and filtered BOD_5 concentrations. Each test was duplicated in a parallel set up. The measurements from these parallel experiments were utilized in estimating the average values. The settling experiments were also repeated several times with samples of raw wastewater under the same conditions to obtain the baseline settling data. The sludge samples used were also analyzed for same parameters as described for the settled sewage samples for carrying out mass balance. The mass balance of parametric values was carried out for the two scenarios- first, representing the modified flow scheme (Figure 4.2) for the observed values; and second set up representing existing flow scheme (Figure 4.3) for calculations based on settled raw sewage parameters and sludge characteristics. The mass balance of solids around PST for modified scheme and existing scheme is described as follows:-

(i) Solids mass balance around PST for modified scheme

$$Q_{pi}.X_{pi} + Q_{rp}.X_{rp} = Q_{pe}.X_{pe} + Q_{pu}.X_{pu}$$

where, Q_{pi} - influent flow rate to PST,

Q_{rp}- return sludge flow rate to PST,

Q_{pe}- Supernatant flow rate from PST to AT,

Q_{pu}- Underflow flow rate from PST (primary sludge)

X_{pi}- solid concentration in influent to PST

X_{rp}- solid concentration in return/excess sludge (added to PST

X_{pe}- solid concentration in supernatant of PST

X_{pu}- Under flow solid concentration of PST

Solids mass balance around PST of existing scheme

$$Q_{pi}.X_{pi} = Q_{pe}.X_{pe} + Q_{pu}.X_{pu}$$

where, Q_{pi}- influent flow rate to PST,

Q_{pe}- Supernatant flow rate from PST to AT,

Q_{pu}- Underflow flow rate from PST (primary sludge)

X_{pi}- solid concentration in influent to PST

X_{pe}- solid concentration in supernatant of PST

X_{pu}- Under flow solid concentration of PST

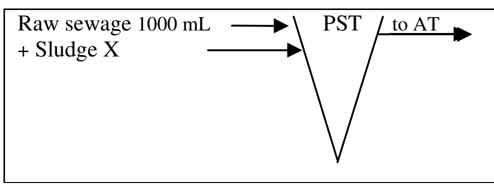


Figure 4.2 Modified scheme of PST

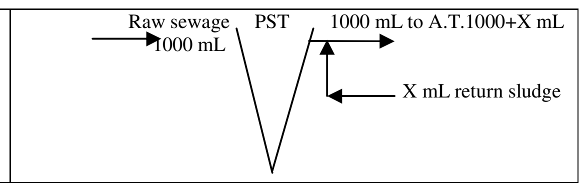


Figure 4.3 Existing scheme of PST

Similar experiments were conducted with thickened return sludge and anaerobically digested sludge of STP Delawas. The experiments were further carried out with the return sludge as well as the aerobically digested sludge obtained from STP Bhramapuri, which is a 27 MLD STP based on extended aeration ASP. All these sludge samples were mixed with 1000 mL of raw sewage of STP Delawas in different proportions and subjected to settling experiments in the manner described above. After observing favorable results with aerobically digested sludge from STP Bhramapuri, the last set of experiments were conducted with briefly aerated thickened excess sludge of STP Delawas for settling analysis.

Hot air oven was used for the measurement of TSS at 105^0 C. BOD_5 was measured at 20°C with Winkler's Azide modified method. COD was analyzed using open reflux method; and for filtered BOD_5, 0.45 micron Millipore filter paper was used. All above tests were conducted at the Laboratory situated in STP premises. For analyzing the samples of different sludges for BOD analysis, a known volume of these was first acidified with H_2SO_4 in order to solubilise the solids and then it was neutralized with NaOH before being put in the BOD bottle for analysis. Results of addition of various types of sludges in controlled volume are summarized and discussed in details in the following sections.

4.2. Results and discussion

4.2.1. Experiments with addition of secondary excess sludge from STP Delawas

The results of the experiments conducted by adding 10-50 mL sludge in 1000 mL of raw sewage are elaborated in this section and the parametric values of observed as well as calculated scenarios have been shown in graphical forms.

4.2.1.1. Settling characteristics of raw sewage

One litre of raw sewage sample was filled in the Imhoff cone (reactor) and samples were drawn from the top surface at intervals of every 30 min for the next 2 h and analyzed for TSS, COD, BOD_5 and filtered BOD_5. The results are listed in Table 4.1.

Table 4.1 Results of settling of raw sewage sample I

Duration, min	TSS, mg/L	TSS removal, %	COD, mg/L	COD removal, %	BOD_5, mg/L	BOD_5 removal, %	Filtered BOD_5 , mg/L	Filtered BOD_5 removal, %
0	496	0	688	0	285	0	83	0
30	230	53	386	46	177	38	79	5
60	210	57	368	46	166	41	74	11
90	206	58	356	48	164	43	72	13
120	196	60	336	51	163	44	63	24

It can be seen from Table 4.1 that the removal of TSS, COD, BOD_5 and filtered BOD_5 in first hour was 57%, 46%, 41% and 11% respectively. After 2 h the additional removal observed in TSS, COD, BOD_5 and filtered BOD_5 was only 3%, 3%, 5% and 13%, indicating marginal difference in settling (entering hindered zone) efficiency but an enhanced removal of soluble substrate during the second hour. The overall filtered BOD_5 removed was 24% after 2 h, which might be due to absorption of soluble organics migrating through the cell wall of bacteria (like the contact tank in contact-stabilization process). The results obtained for raw sewage settling were used as the baseline settling data for the calculations representing existing flow scheme of the STP.

4.2.1.2.Characteristics of excess sludge used for the settling experiments

The characteristics of raw sewage and return/excess sludge used for experiment as per procedure above are listed in Table 4.2. The results of settling of raw sewage are listed in Table 4.3.

Table 4.2 Characteristics of excess sludge of STP Delawas

Parameters	Excess/return sludge
TSS, mg/L	7750
COD, mg/L	1630
BOD_5, mg/L	618
Filtered BOD_5, mg/L	165

Table 4.3 Results of settling of raw sewage sample II

Duration, min	TSS, mg/L	TSS removal, %	COD, mg/L	COD removal, %	BOD_5, mg/L	BOD_5 removal, %	Filtered BOD_5, mg/L	Filtered BOD_5 removal, %
0	576	0	768	0	300	0	89	0
30	245	57%	402	48%	185	38%	81	9%
60	226	61%	380	51%	172	43%	75	16%
90	218	62%	367	52%	167	44%	71	20%
120	201	65%	348	55%	164	45%	67	25%

Parameters were observed for the mixture of 1010 mL, raw sewage (1000 mL-sample-I) and return sludge (10 mL) after 0, 30, 60, 90, and 120 min of settling. The values have been calculated assuming that 10 mL of return sludge was directly reaching the aeration tank and 1000 mL of raw sewage was entering the aeration tank after plain settling in PST as per the existing flow scheme at the STP. The parametric values for TSS, COD, BOD_5 and filtered BOD_5 were calculated for settling time of 30, 60, 90 and 120 min by adding the settled values of these parameters for 1000 mL raw sewage. The results of the experiments obtained after addition of return/excess sludge in 10 mL with 1000 mL of raw sewage were compared with the calculated values for TSS, COD, BOD_5, and filtered BOD_5 in the modified scenario are shown in Figures 4.4 to 4.7. Observed values and calculated values also shown at Appendix 3.

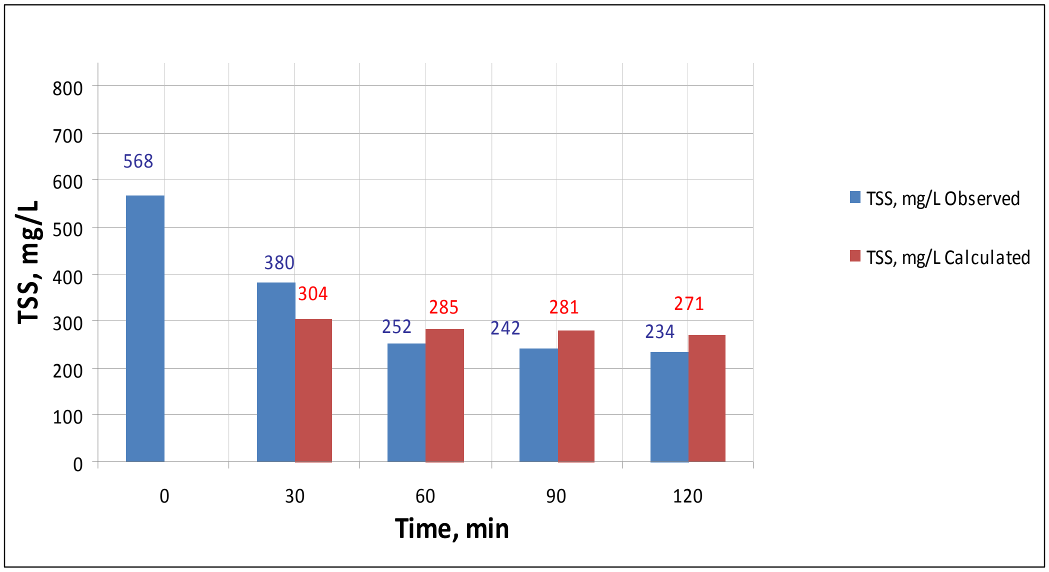


Figure 4.4 TSS removal with 10 mL return sludge

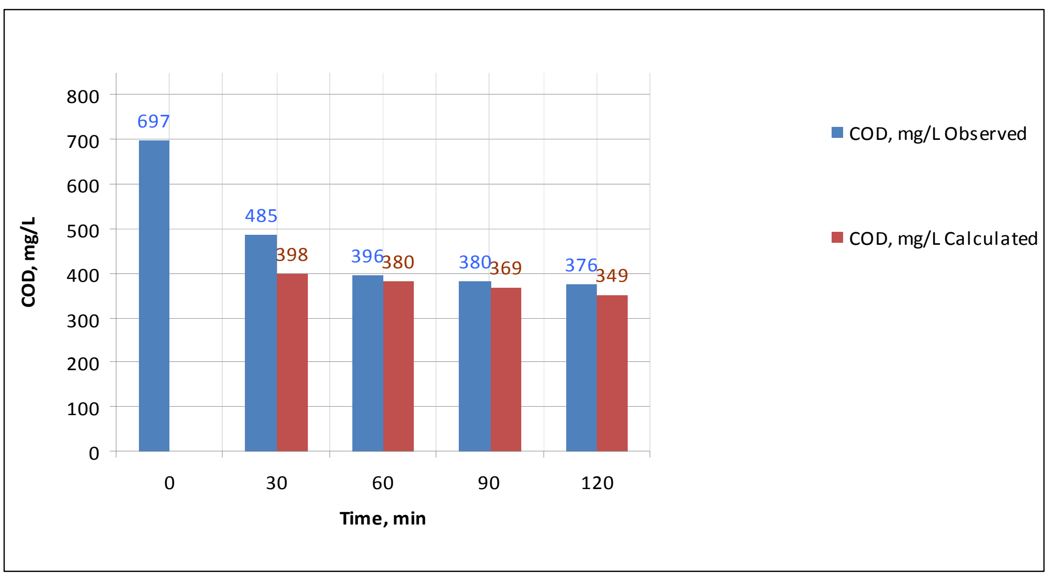


Figure 4.5 COD removal with 10 mL return sludge

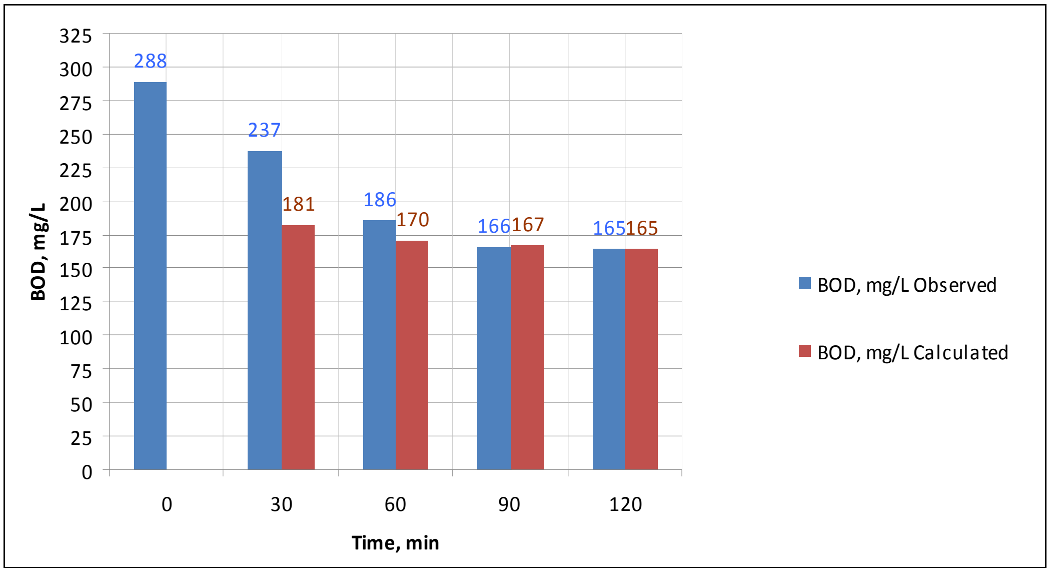


Figure 4.6 BOD removal with 10 mL return sludge

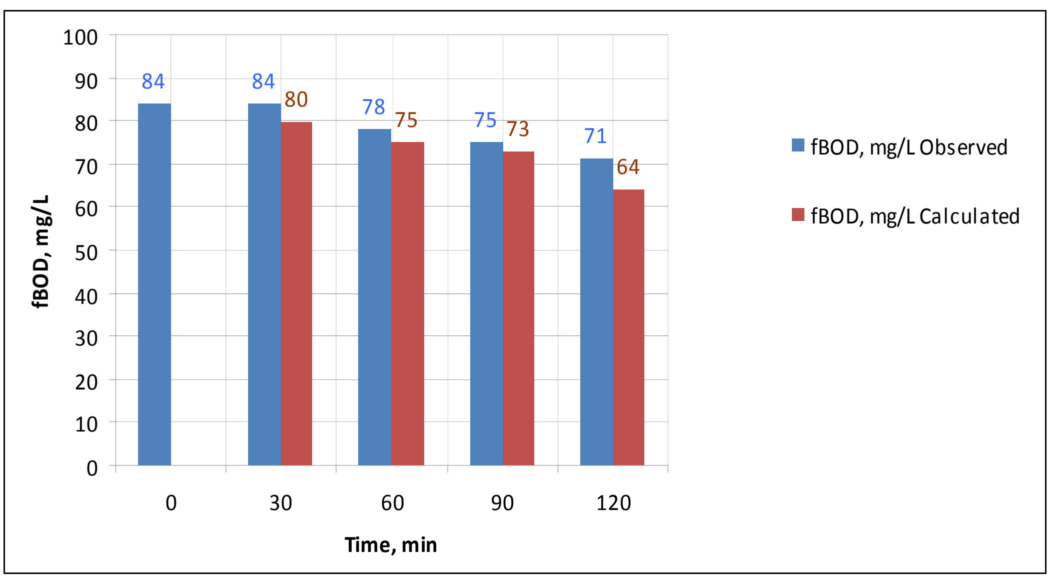


Figure 4.7 fBOD removal with 10 mL return sludge

It can be seen that the observed removal of TSS, COD, BOD_5 and filtered BOD_5 in first hour was 56 %, 43%, 35 % and 7% respectively indicating that first hour is more important in the removal of TSS, COD and BOD_5. In the second hour the additional removal in TSS, COD, BOD_5 and filtered BOD_5 observed was 2%, 3%, 7% and 16 % respectively in these parameters. It indicated that the second hour was more effective in the removal of filtered BOD (soluble fraction) probably due to the absorption into the cells.

The calculated values as per mass balancing of settled parameters of 1000 mL of raw sewage added with those of 10 mL return sludge showed removal of TSS, COD, BOD_5 and filtered BOD_5 in first hour as 49%, 45%, 41% and 9 % respectively. In the second hour the calculated additional removal in these were 3%, 4%, 1% and 4% respectively. It can be seen that the observed removals were higher than the corresponding calculated values probably due to unfavorable cell physiology. The total observed percentage removals after 2 h of settling for TSS, COD, BOD_5 and filtered BOD_5 were 58%, 46%, 42% and 23% respectively, while the corresponding calculated values (representing existing flow scheme) were 52%, 49%, 42% and 13% respectively. It shows that the addition of 10 mL return sludge did not respond favorably except for TSS removal and hence the proportion of sludge addition was increased in the subsequent experiments.

Similar experiments were conducted with 20, 30, 40, and 50 mL of excess sludge addition to 1000 mL of raw sewage. The results of settling analysis of these experiments are shown in Figures 4.8- 4.23.

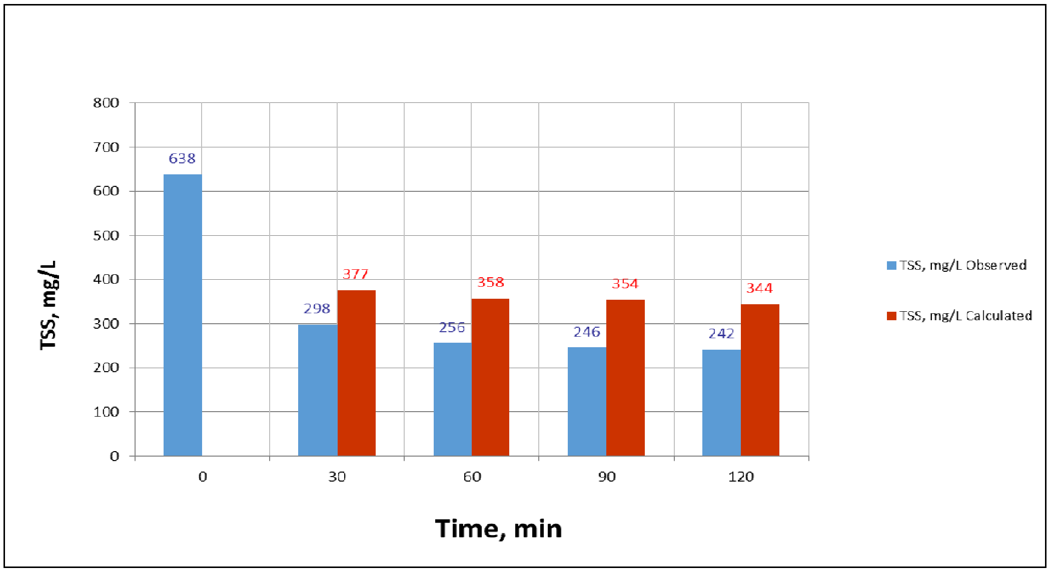


Figure 4.8 TSS removal with 20 mL return sludge

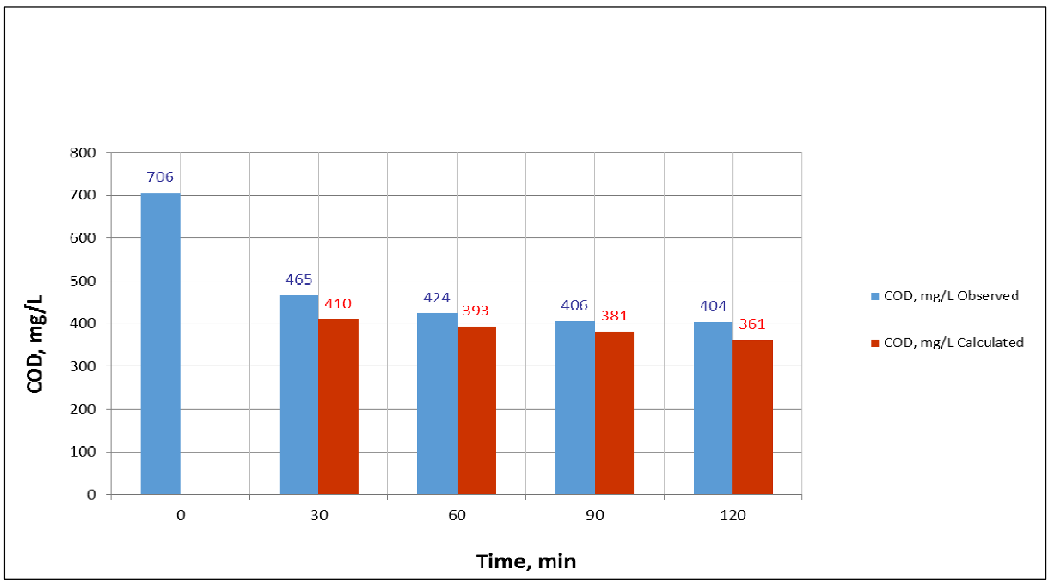


Figure 4.9 COD removal with 20 mL return sludge

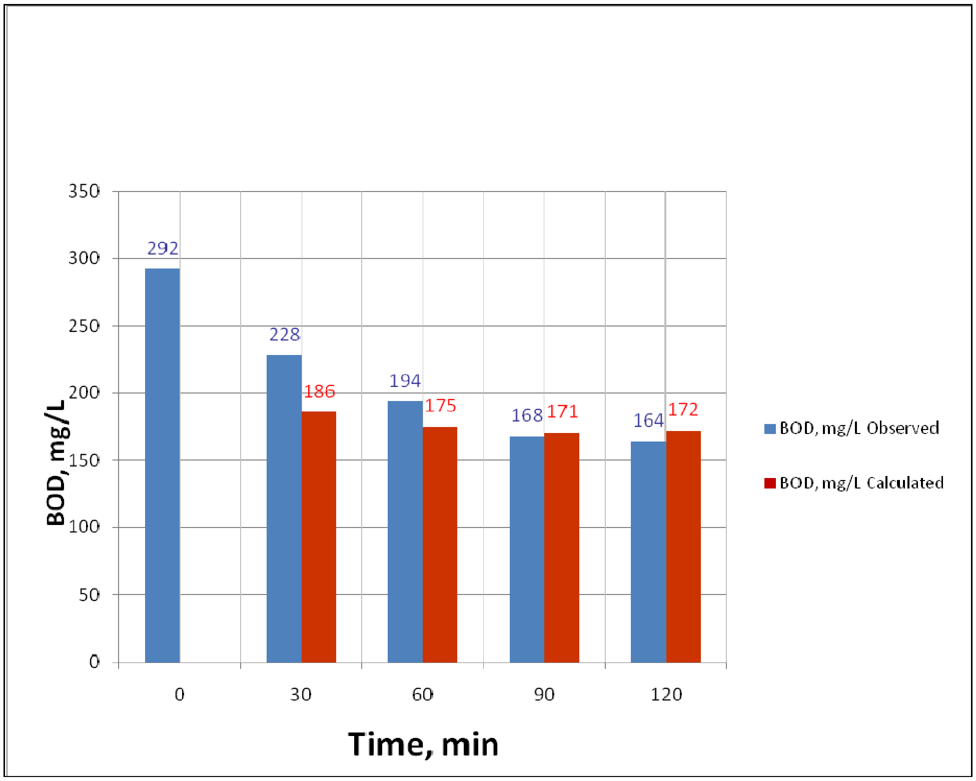


Figure 4.10 BOD removal with 20 mL return sludge

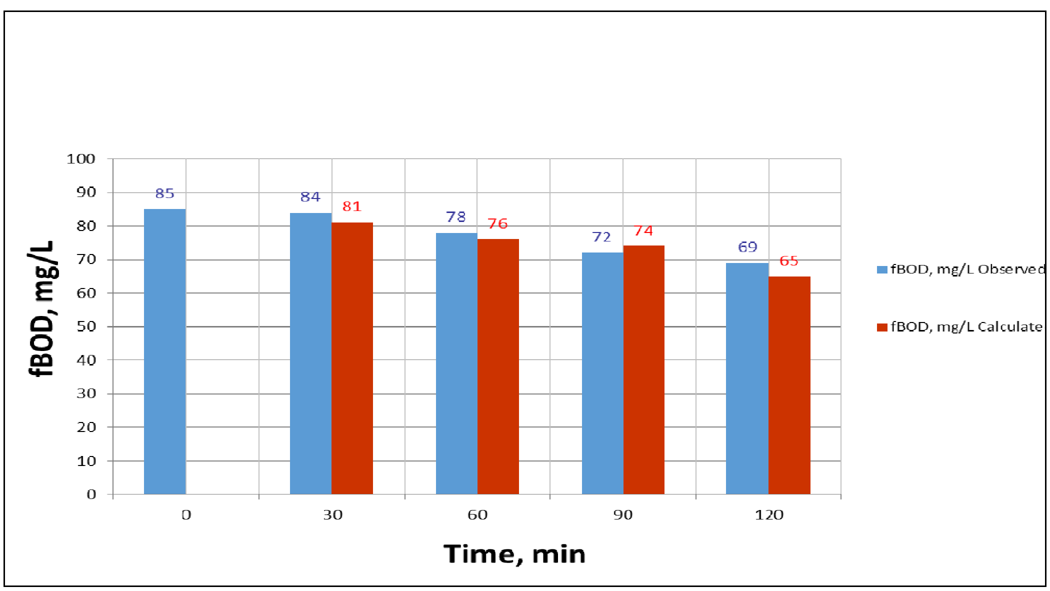


Figure 4.11 fBOD removal with 20 mL return sludge

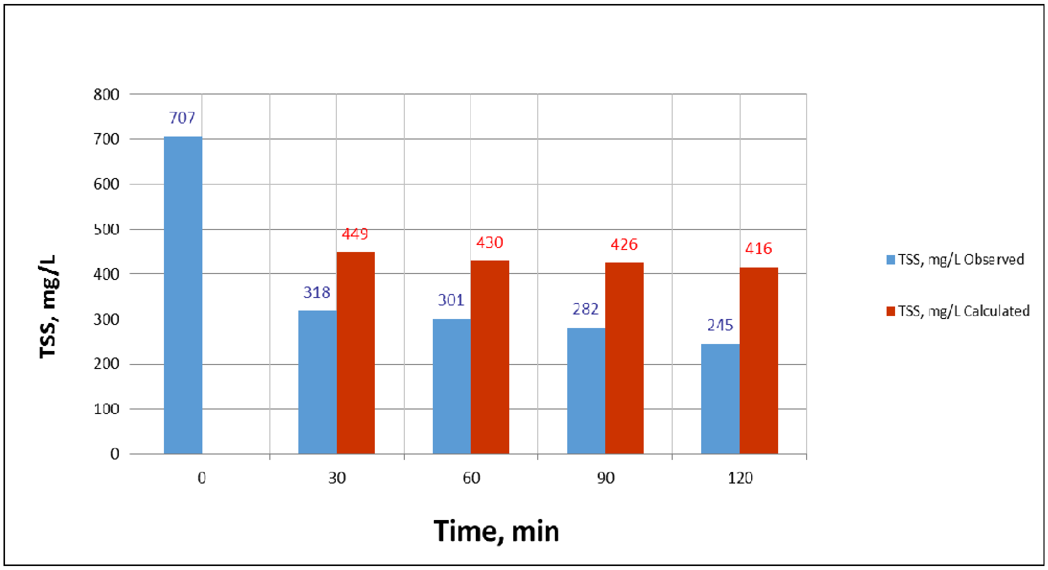


Figure 4.12 TSS removal with 30 mL return sludge

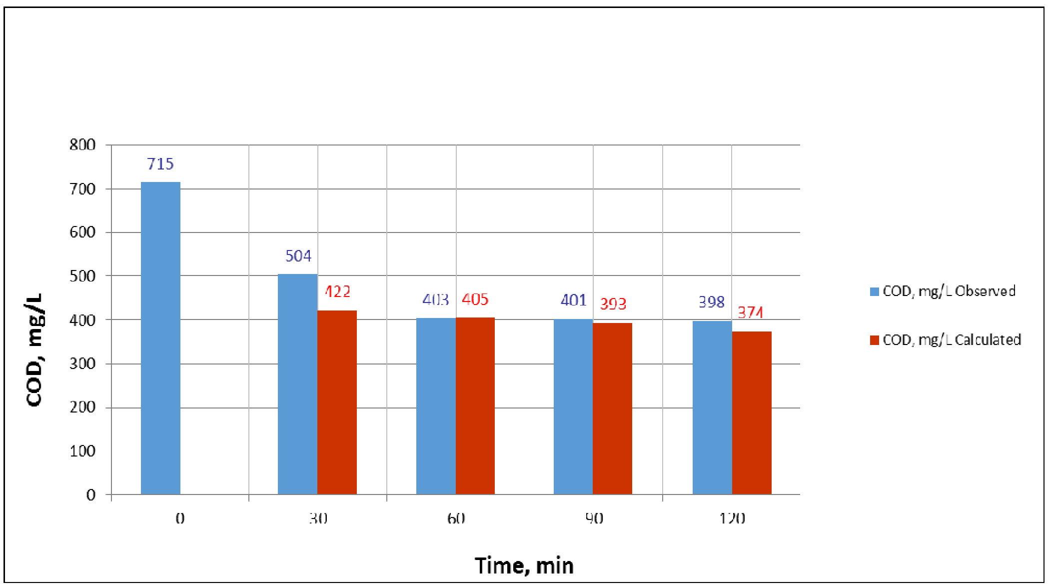


Figure 4.13 COD removal with 30 mL return sludge

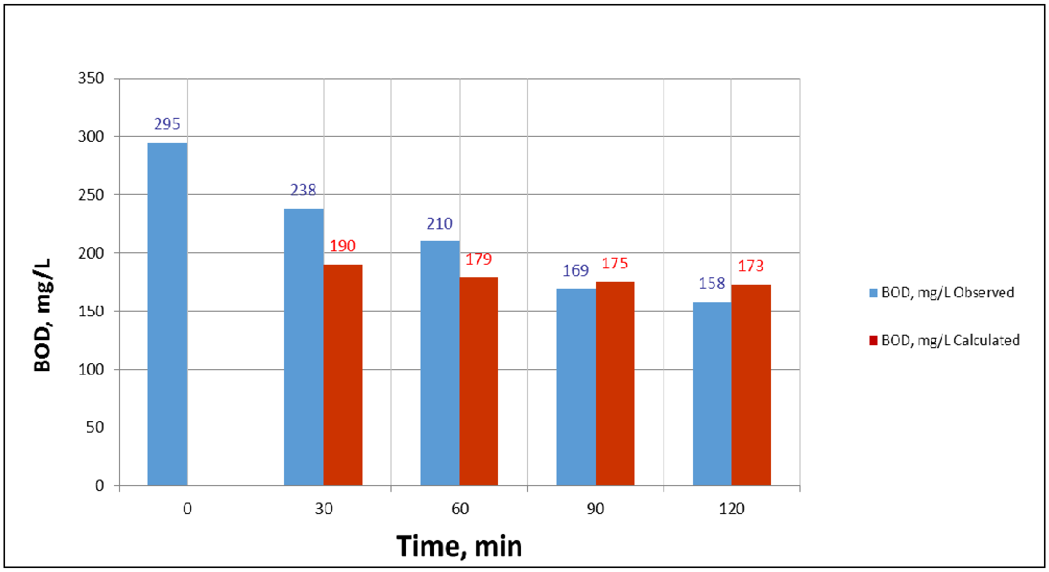


Figure 4.14 BOD removal with 30 mL return sludge

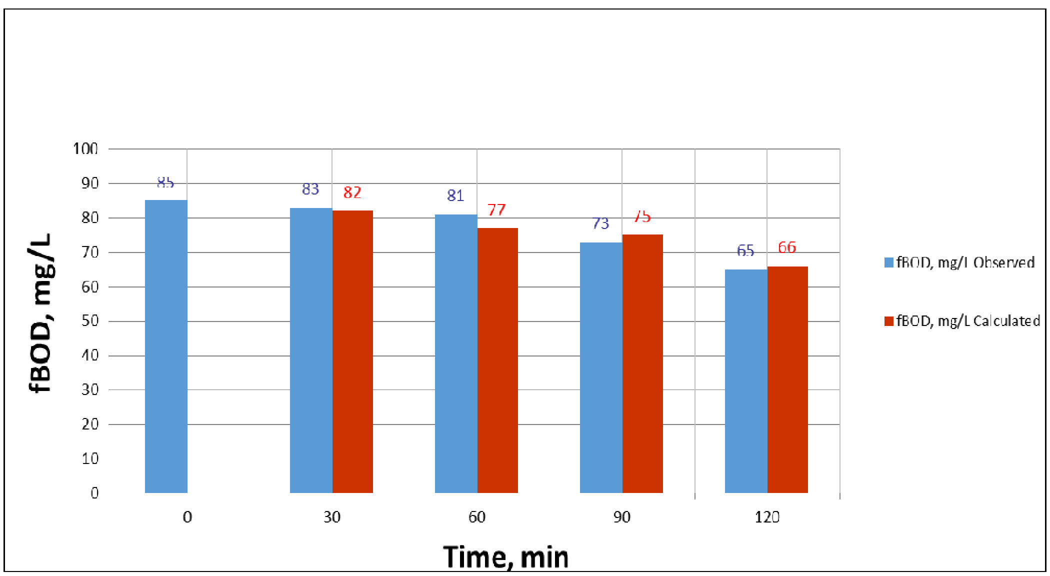


Figure 4.15 fBOD removal with 30 mL return sludge

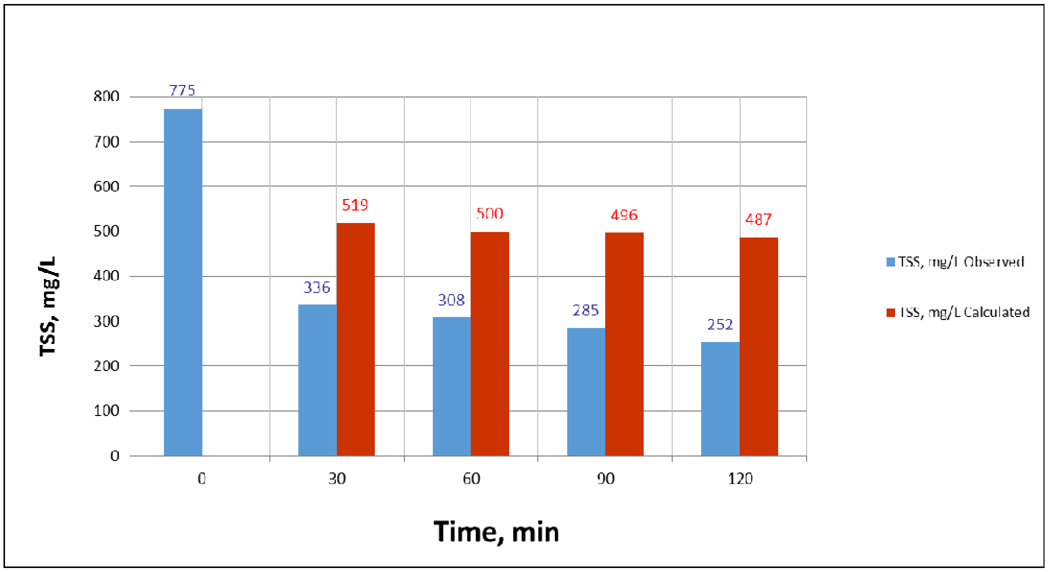


Figure 4.16 TSS removal with 40 mL return sludge

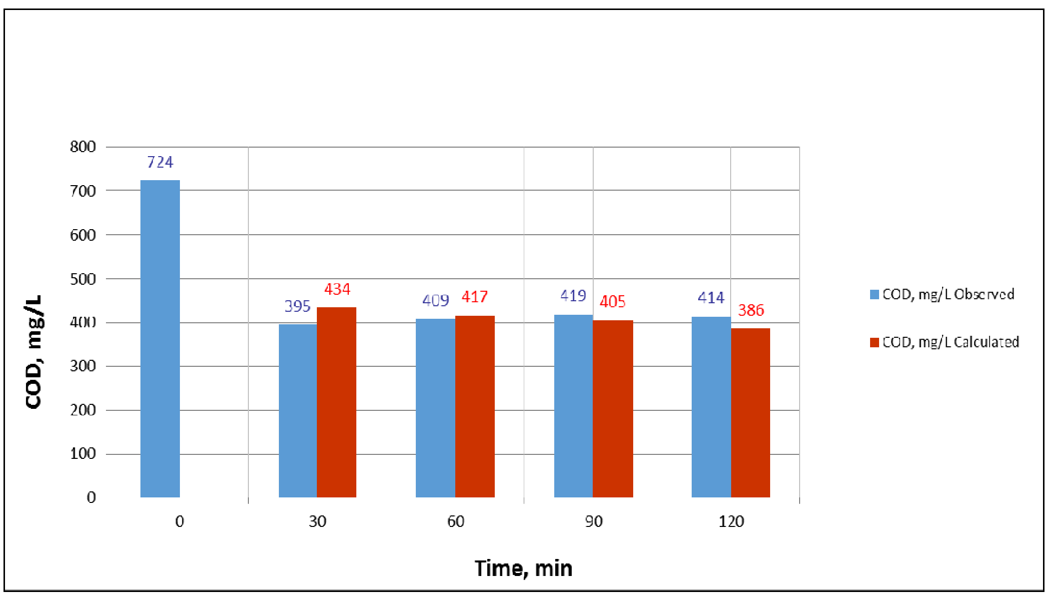


Figure 4.17 COD removal with 40 mL return sludge

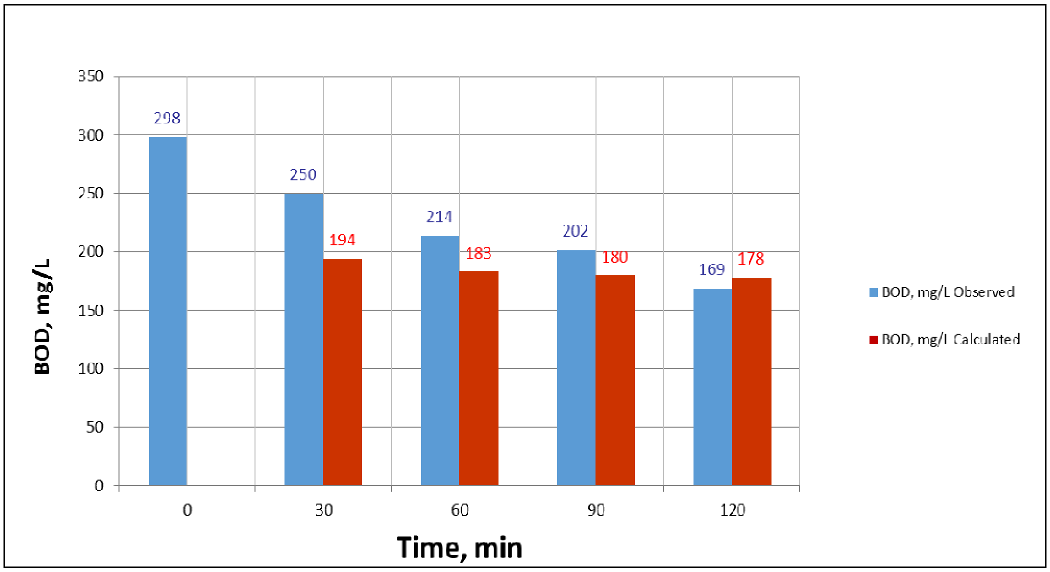


Figure 4.18 BOD removal with 40 mL return sludge

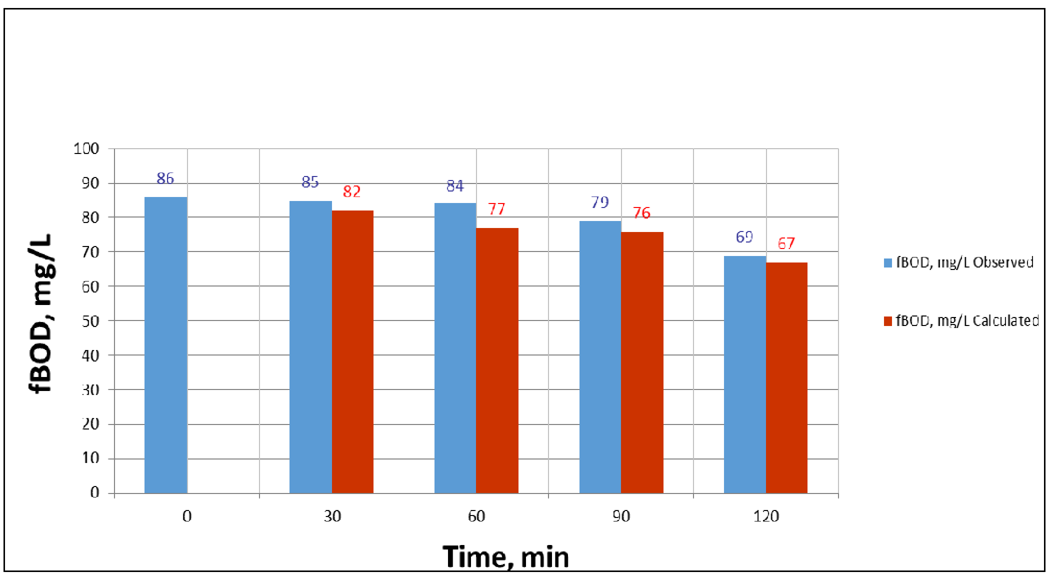


Figure 4.19 fBOD removal with 40 mL return sludge

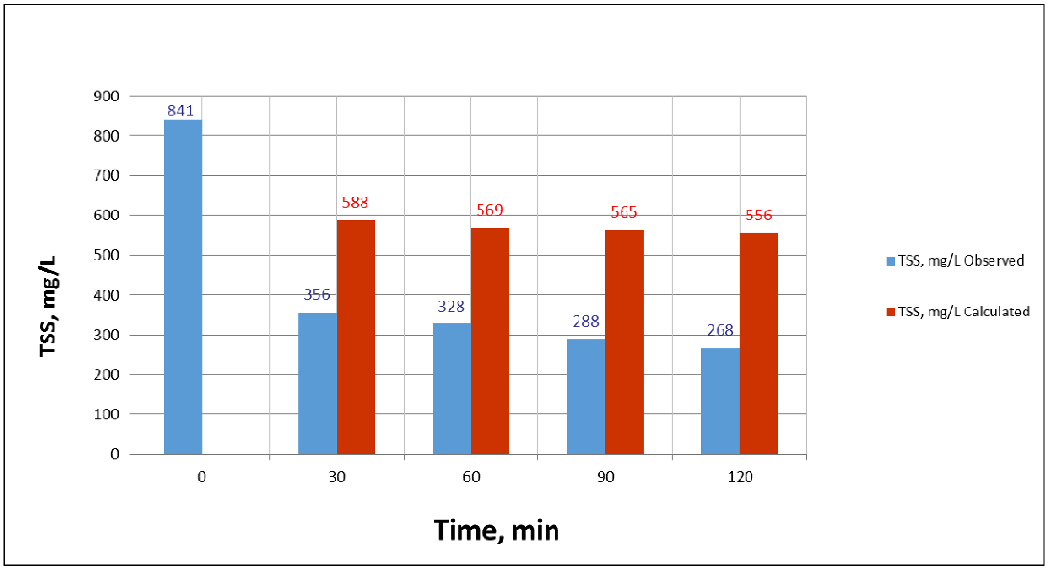


Figure 4.20 TSS removal with 50 mL return sludge

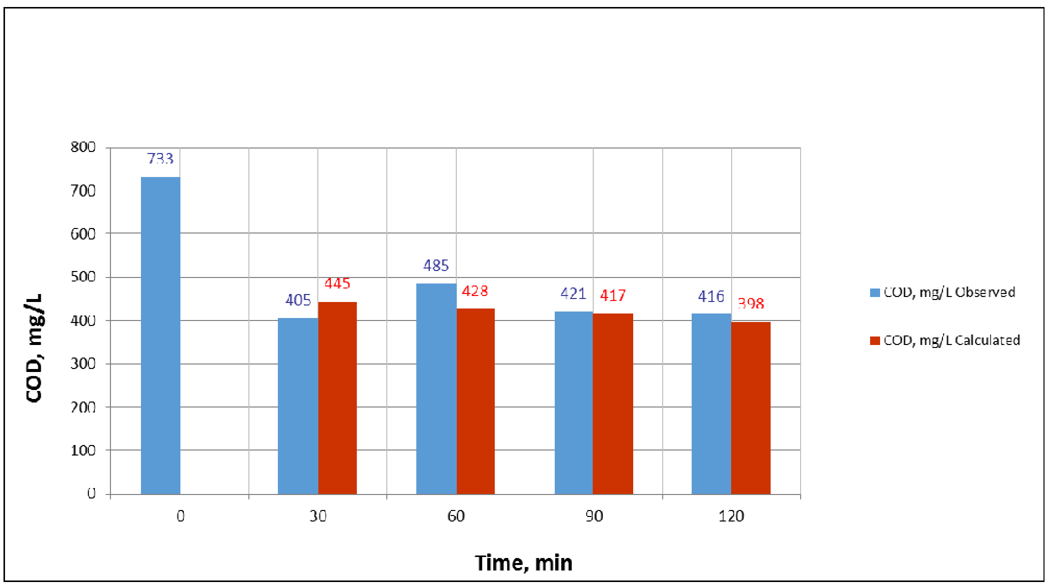


Figure 4.21 COD removal with 50 mL return sludge

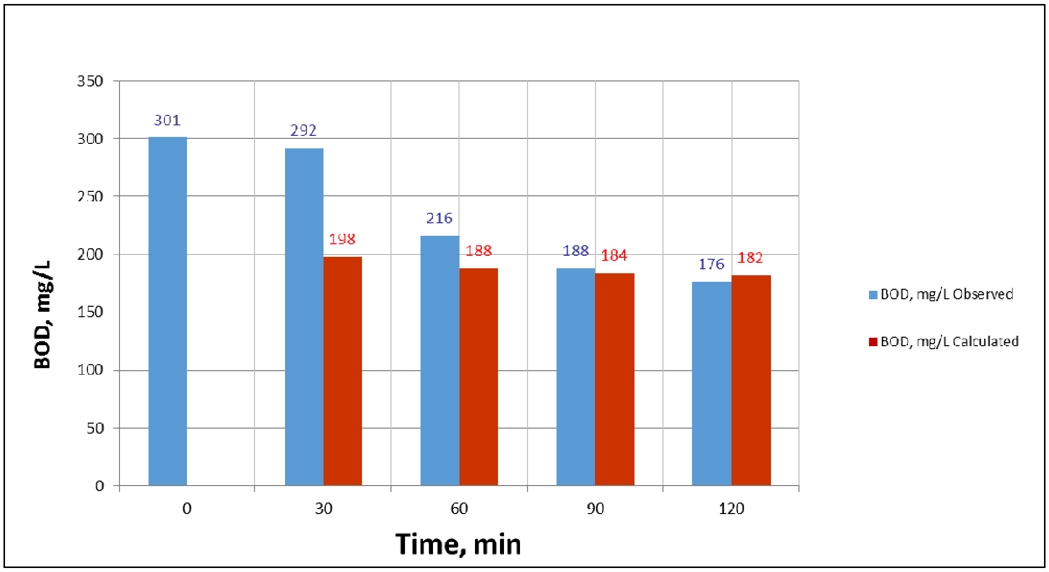


Figure 4.22 BOD removal with 50 mL return sludge

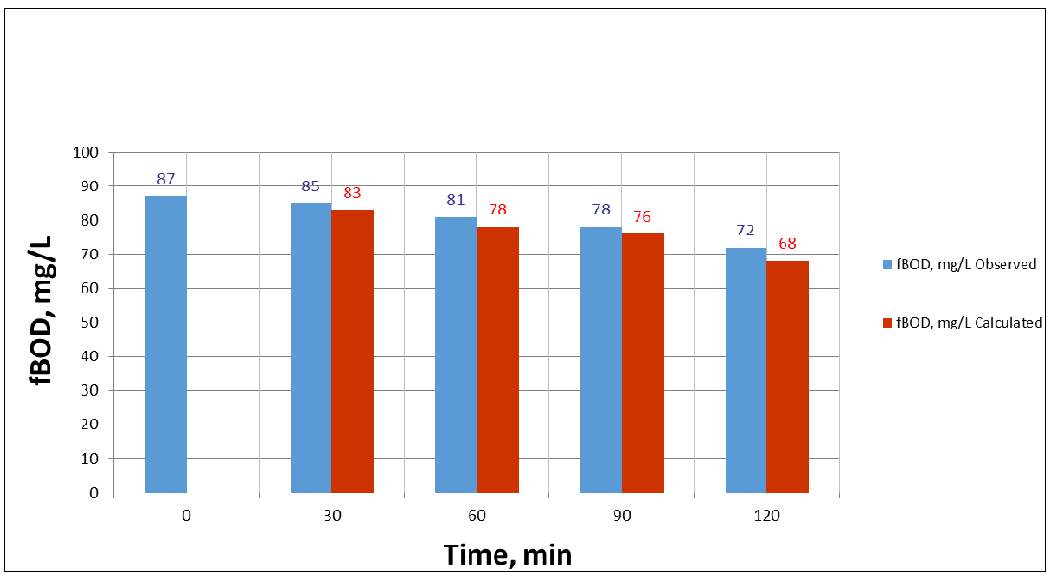


Figure 4.23 fBOD removal with 50 mL return sludge

It can be seen from these Figures4.8 to 4.23 that the observed percentage removal after first 1 h of settling for TSS, COD, BOD and filtered BOD were in the range of 57- 68%, 40-44%, 34-42% and 17-8 % respectively. The corresponding calculated removals in these parameters were in the range of 39-44 %, 42-44%, 40-38% and 9-11% respectively. The maximum TSS removal was observed with 50 mL sludge addition for 2 h settling period showing the effect of flocculation obtained through the addition of secondary excess sludge. The observed TSS removals were much higher than their corresponding values calculated for the existing scenario confirming the benefits in terms of removal of much finer suspensions in the modified scheme. The maximum COD removal was observed as 44% with 30 mL as well as 40 mL sludge addition at 2 h settling period, which was comparable to the calculated scenario thereby showing no additional benefit due to the modified process. The maximum BOD and fBOD removals were 46% and 24% respectively, which were for the case of 30 mL sludge addition at 2 h settling. This showed some improvement in the modified scheme for total BOD removal but a significant gain in terms of filtered BOD removal obtained due to absorption of soluble substrate in to the microbial cells. Among the above experiments, the observed values for 30 mL sludge addition were most favorable for the removal of TSS, COD, BOD and fBOD.

The results indicated that sludge as flocculent can be useful, though the incremental removals were not very high probably due to physiological conditions of sludge not being very good for the reasons cited earlier. Thus it was decided to repeat the experiments with other available sludges from STP Delawas and STP Brahmapuri as described earlier. The results of these experiments are shown in the following sections.

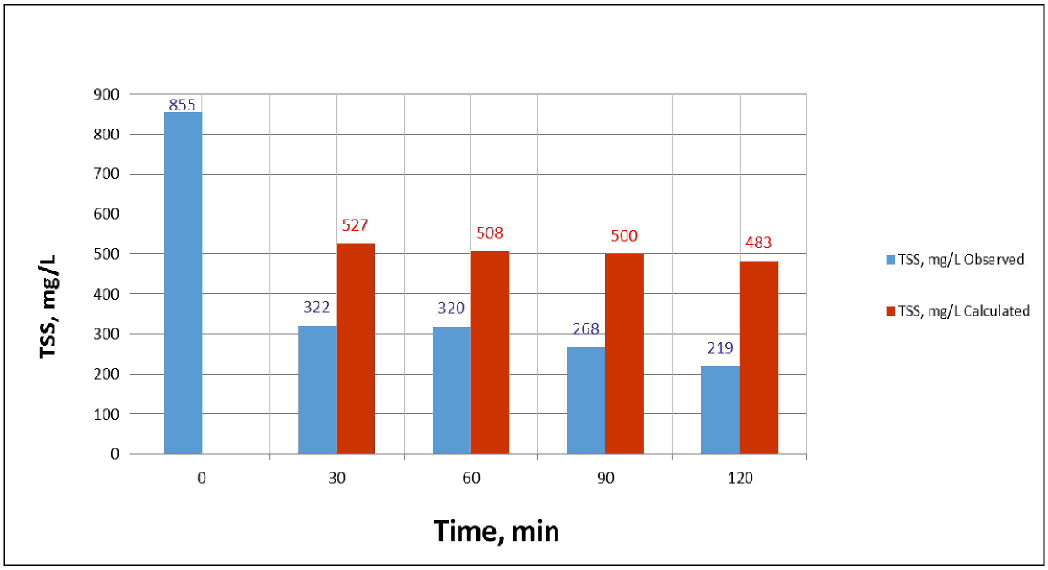
4.2.2. Settling experiments with thickened sludge from STP Delawas

One litre of raw sewage sample –II was added with thickened excess sludge in 10, 20, 30, 40 and 50 mL volumes and the settling test was repeated. The settling characteristics of raw sewage used in this experiment are represented in Table 4.3 and the properties of thickened excess sludge are represented in Tables 4.4.

Table 4.4 Characteristics of raw sewage and thickened excess sludge of STP Delawas

Parameters	Thickened sludge of STP Delawas
TSS, mg/L	28756
COD, mg/L	7226
BOD_5 , mg/L	825
Filtered BOD, mg/L	142

The results of settling analysis of these experiments are shown in Figures 4.24 – 4.43.



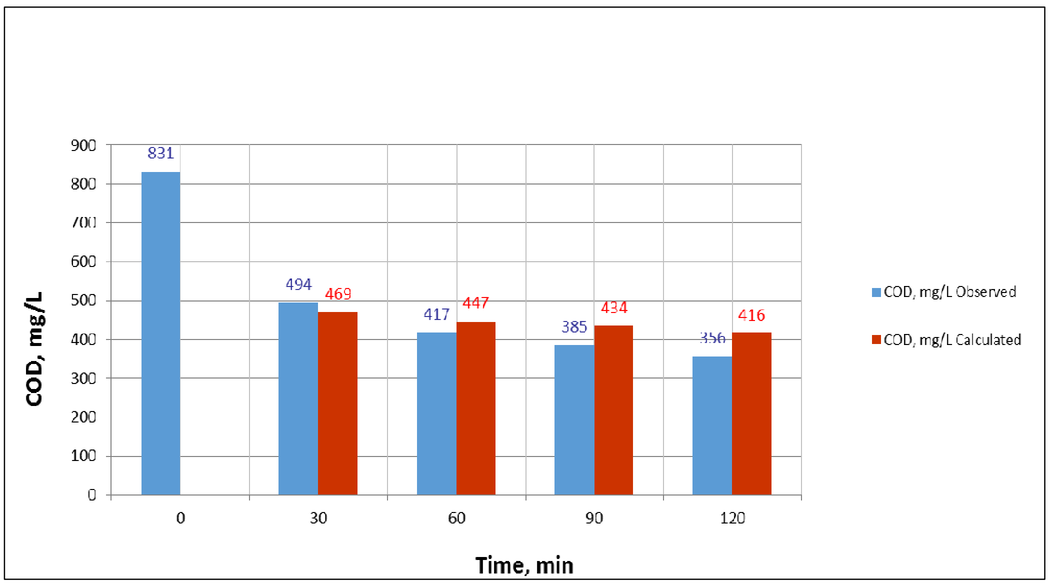


Figure 4.24 TSS removal with 10 mL thickened sludge

Figure 4.25 COD removal with 10 mL thickened sludge

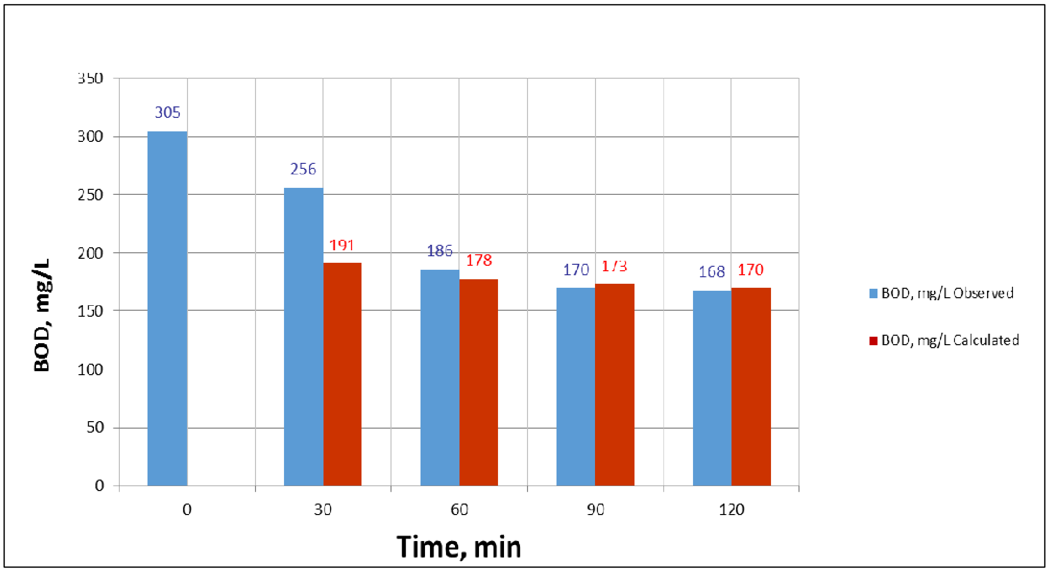


Figure 4.26 BOD removal with 10 mL thickened sludge

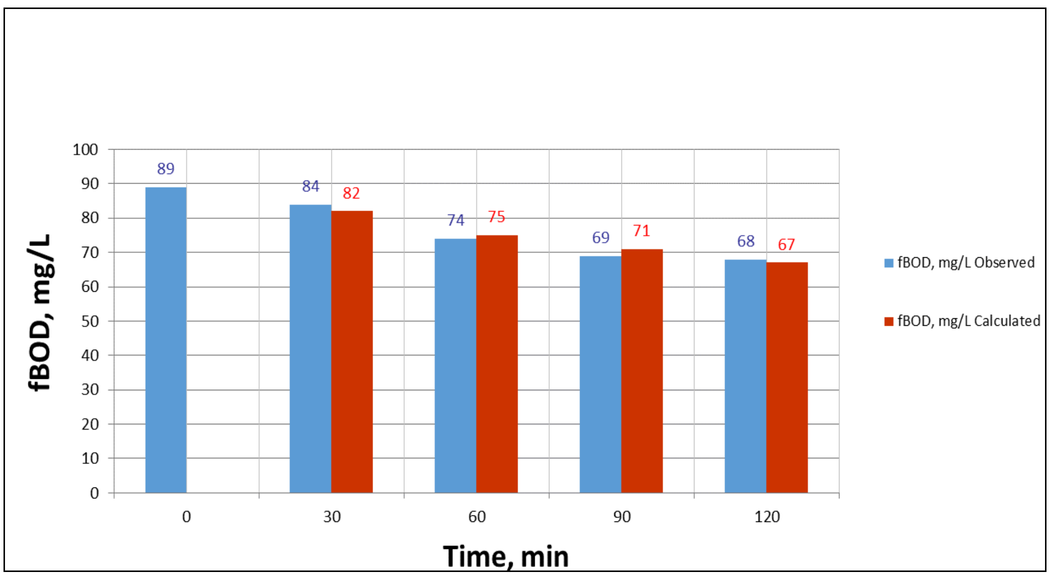


Figure 4.27 fBOD removal with 10 mL thickened sludge

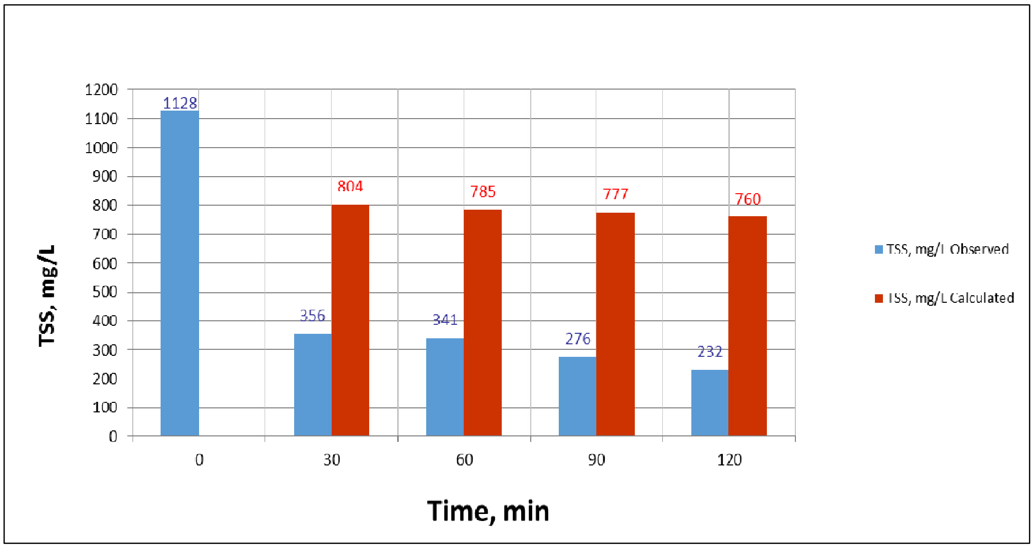


Figure 4.28 TSS removal with 20 mL thickened sludge

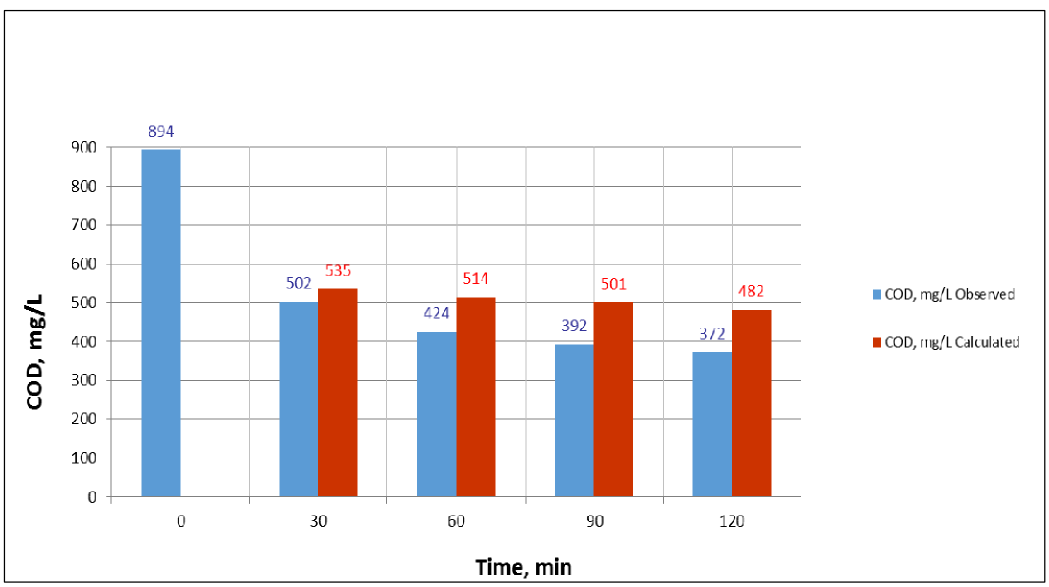


Figure 4.29 COD removal with 20 mL thickened sludge

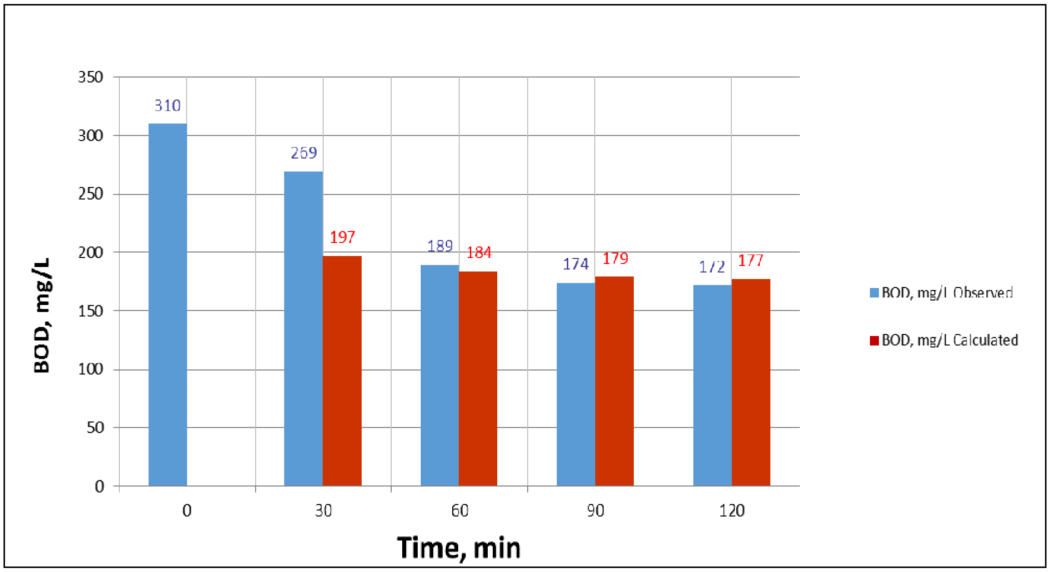


Figure 4.30 BOD removal with 20 mL thickened sludge

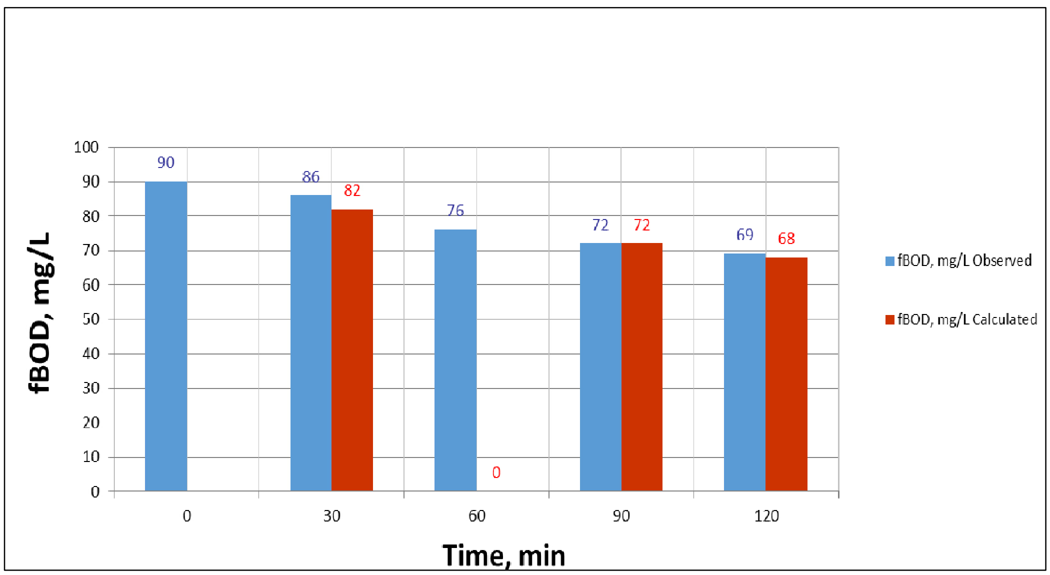


Figure 4.31 fBOD removal with 20 mL thickened sludge

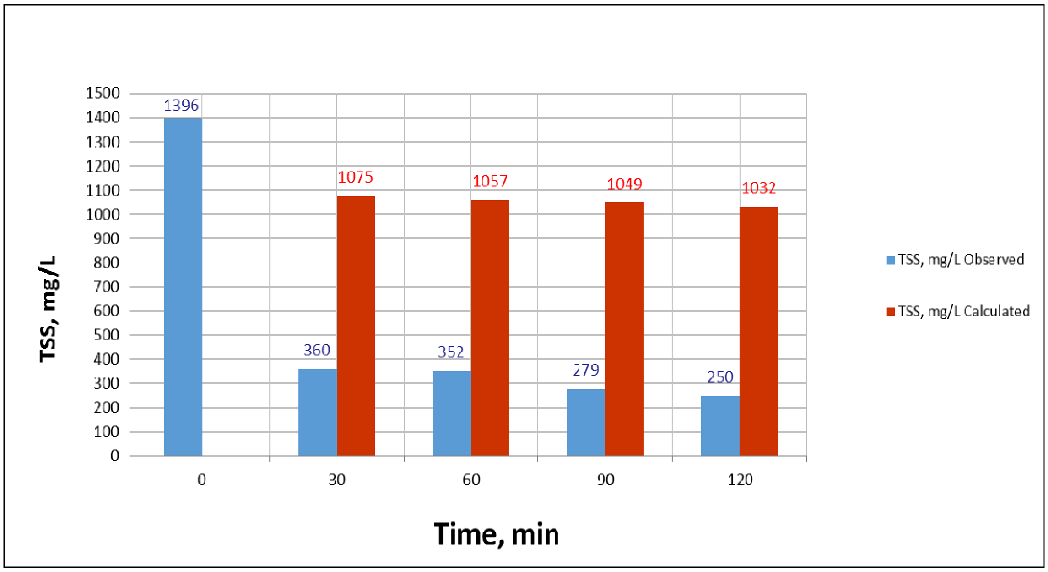


Figure 4.32 TSS removal with 30 mL thickened sludge

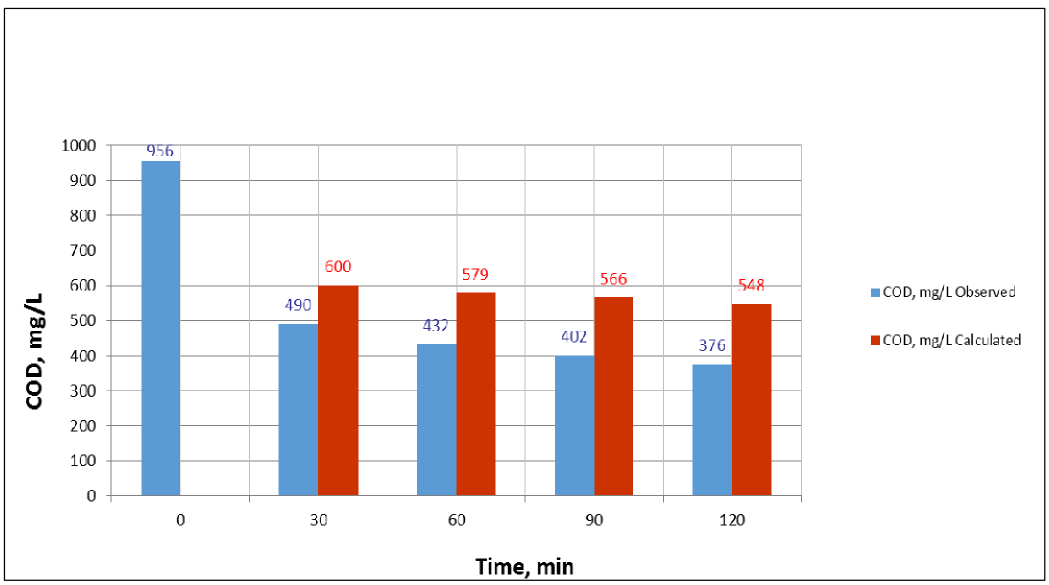


Figure 4.33 COD removal with 30 mL thickened sludge

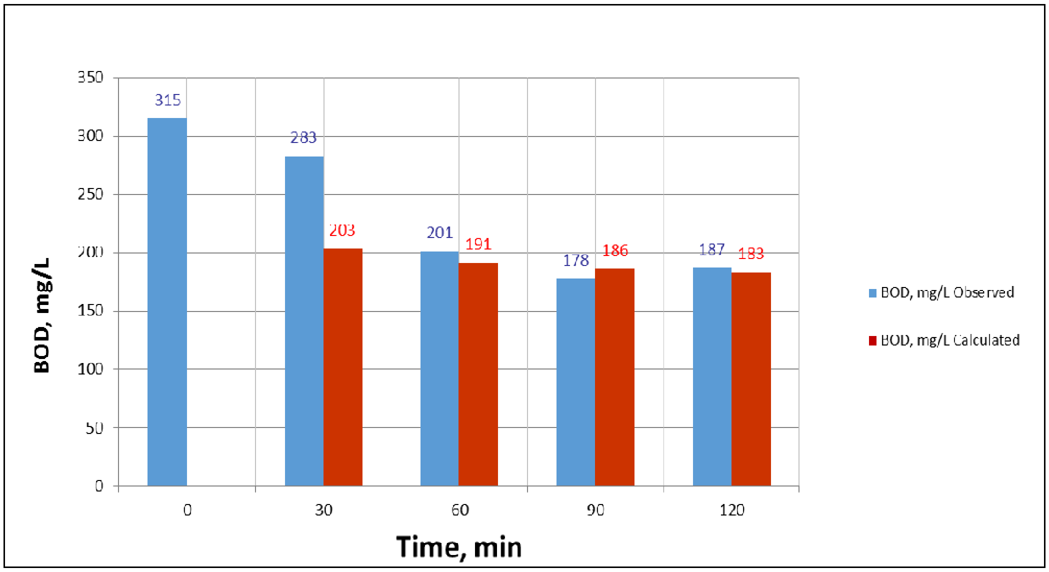


Figure 4.34 BOD removal with 30 mL thickened sludge

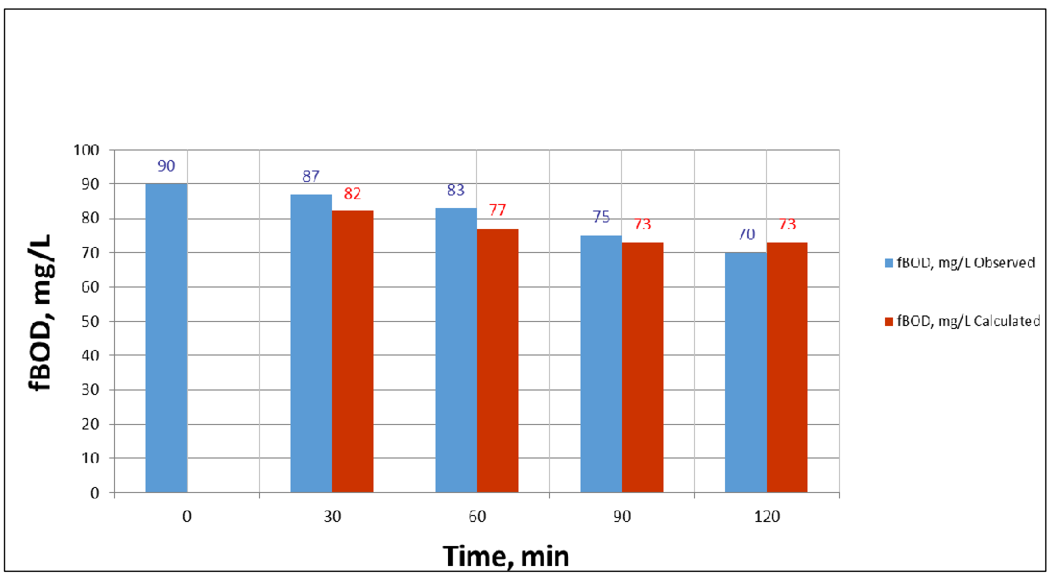


Figure 4.35 fBOD removal with 30 mL thickened sludge

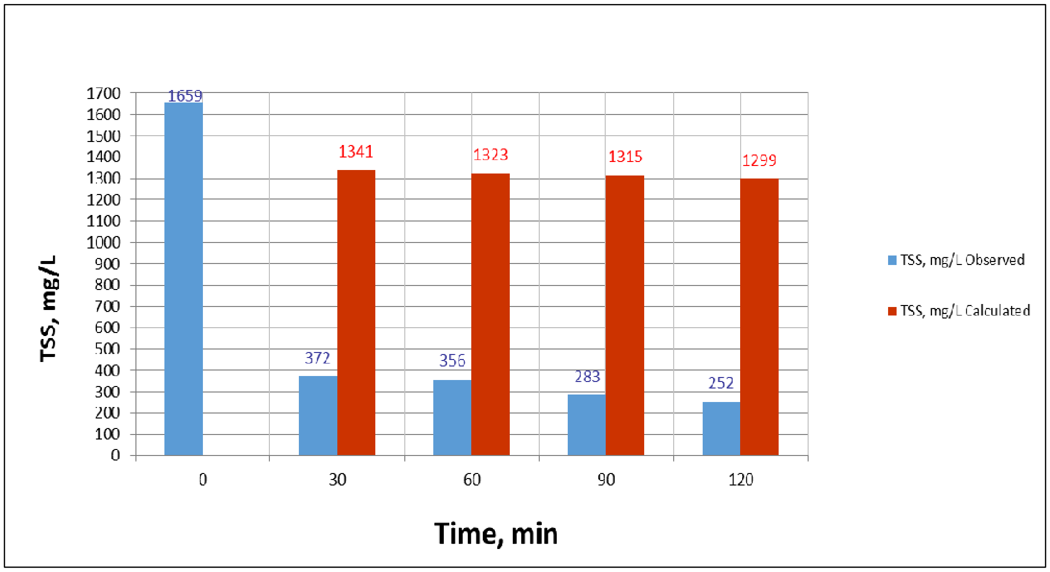


Figure 4.36 TSS removal with 40 mL thickened sludge

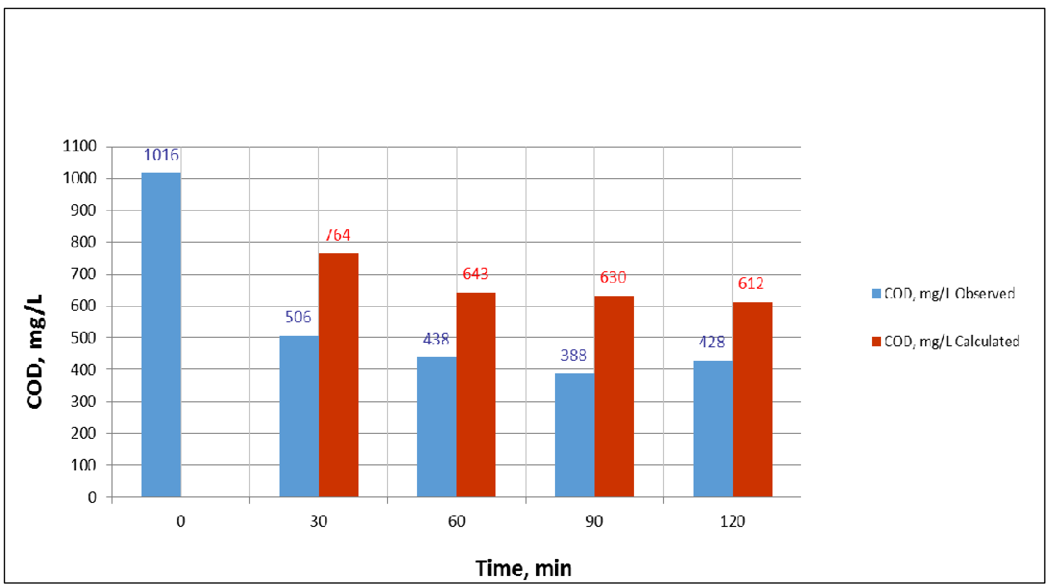


Figure 4.37 COD removal with 40 mL thickened sludge

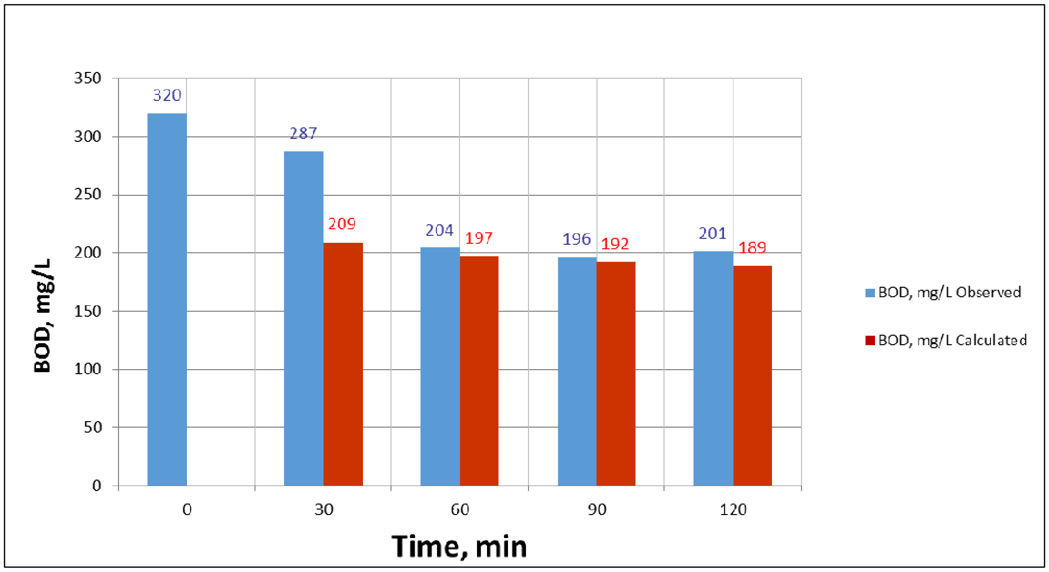


Figure 4.38 BOD removal with 40 mL thickened sludge

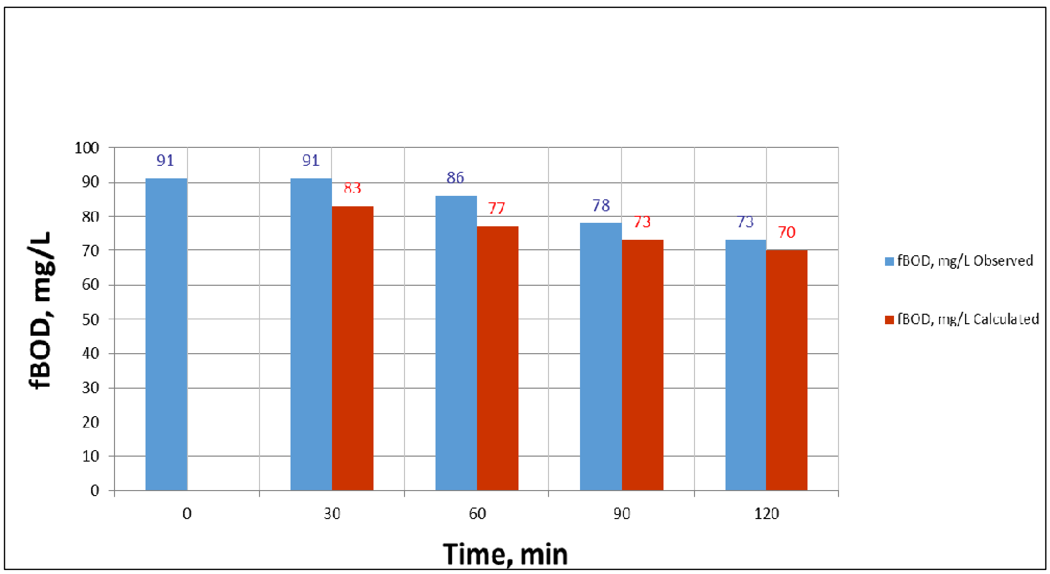


Figure 4.39 fBOD removal with 40 mL thickened sludge

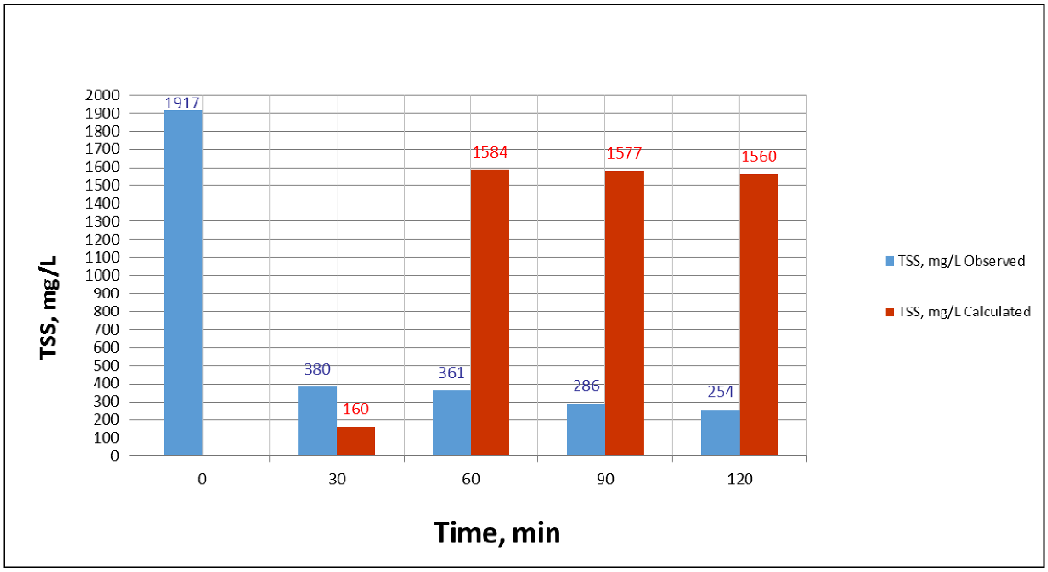


Figure 4.40 TSS removal with 50 mL thickened sludge

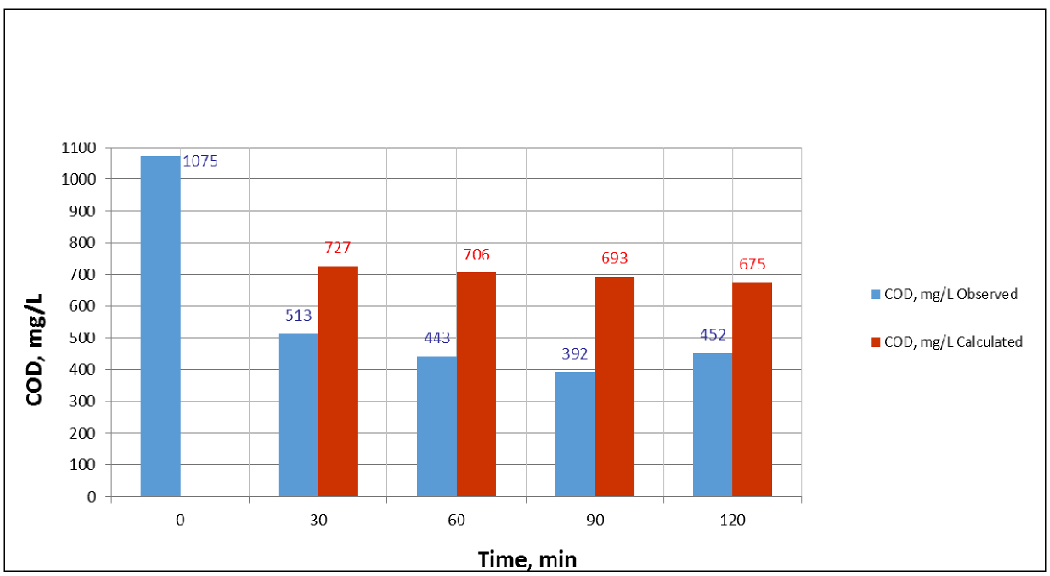


Figure 4.41 COD removal with 50 mL thickened sludge

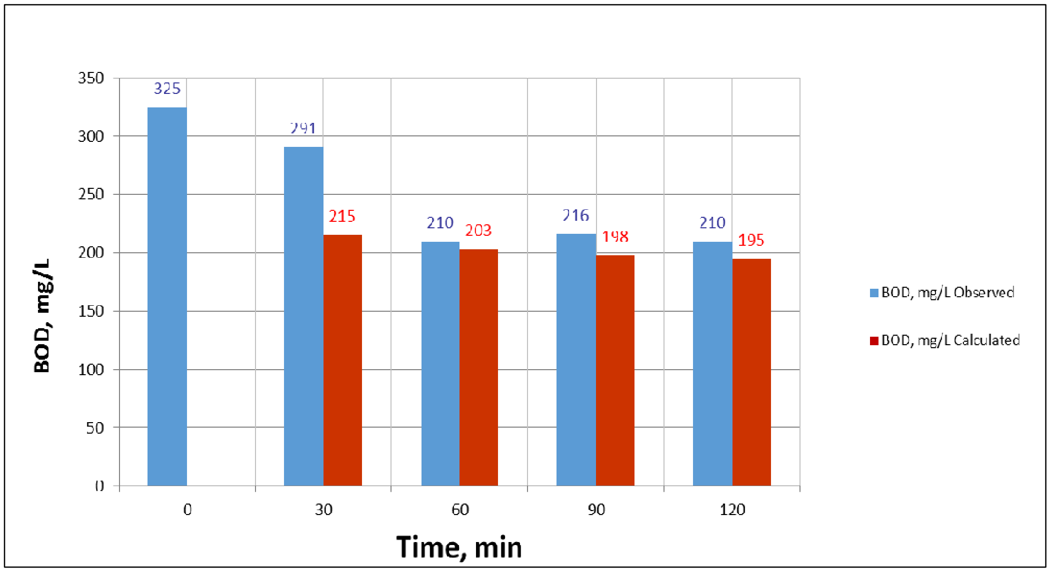


Figure 4.42 BOD removal with 50 mL thickened sludge

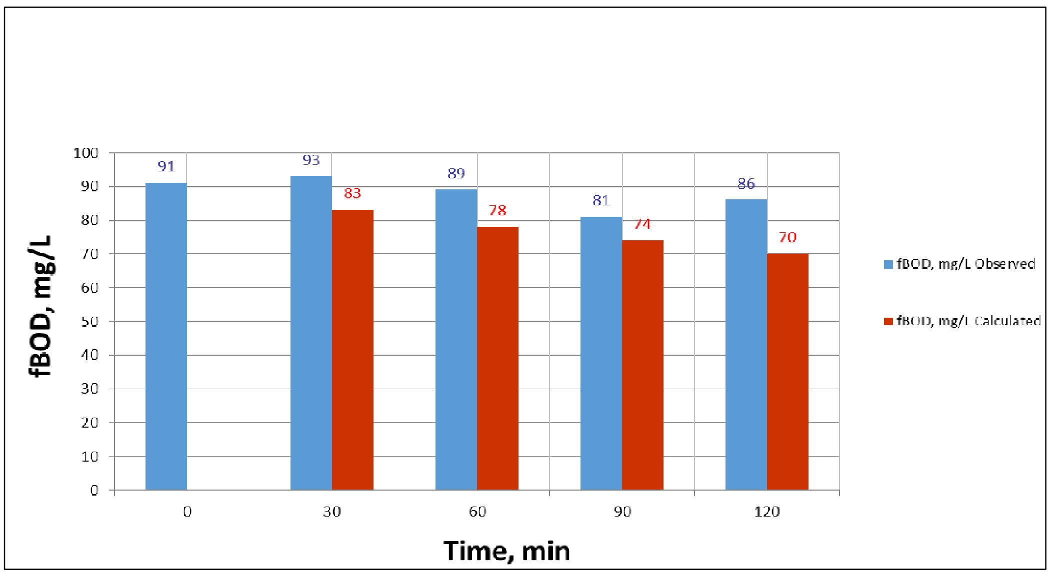


Figure 4.43 fBOD removal with 50 mL thickened sludge

It can be seen from Figure 4.24 to 4.43 that the observed percentage removal after first 1 h of settling for TSS, COD, BOD and filtered BOD were in the range of 63-81-%, 50-59%, 35-39 % and 2-16 % respectively. The corresponding calculated removals in these parameters were in the range of 17-41 %, 34-44%, 35-42 % and 14-16% respectively. The maximum TSS removal was observed with 50 mL sludge addition for 2 h settling period showing the effect of flocculation obtained through the addition of secondary excess sludge. The observed TSS removals were much higher than their corresponding values calculated for the existing scenario confirming the benefits in terms of removal of much finer suspensions in the modified scheme. The maximum COD removal was observed as 61% with 50 mL sludge addition at 2 h settling period, which was also much higher than the calculated maximum value of 50% for 2 h settling with 10 mL sludge thereby showing significant additional benefit due to the modified process. The maximum BOD and fBOD removals were 45% and 24% respectively, which were for the case of 10 mL sludge addition at 2 h settling. These values were comparable to the calculated values for the simulated existing scenario. Among the above experiments, the observed values for 10 mL sludge addition were most favorable for the removal of TSS and COD.

4.2.3. Settling experiments with anaerobically digested sludge from STP Delawas

Similar experiments were conducted with addition of anaerobically digested sludge available at STP Delawas in 10, 20, 30, 40 and 50 mL volumes in 1000 mL of raw sewage. The settling characteristics of raw sewage sample-III and properties of anaerobically digested sludge used in experiment are presented in Tables 4.5 and 4.6

Table 4.5 Results of settling of raw sewage sample III

Duration, min	TSS, mg/L	TSS removal, %	COD, mg/L	COD removal, %	BOD_5, mg/L	BOD_5 removal, %	Filtered BOD_5, mg/L	Filtered BOD_5 removal, %
0	524	0	680	0	288	0	81	0
30	230	56%	392	42%	183	36%	80	1%
60	220	58%	371	45%	170	41%	76	6%
90	206	61%	360	47%	164	43%	73	10%
120	203	61%	340	50%	162	44%	65	20%

Table 4.6 Characteristics of anaerobically digested sludge of STP Delawas

Parameters	**anaerobic digested sludge of STP Delawas**
TSS, mg/L	18372
COD, mg/L	1728
BOD_5, mg/L	610
Filtered BOD_5, mg/L	171

The results obtained with addition of 10 mL, 20 mL, 30 mL, 40 mL and 50 mL anaerobically digested sludge of STP Delawas in 1000 mL raw sewage are shown in Figures 4.44 to 4.63:

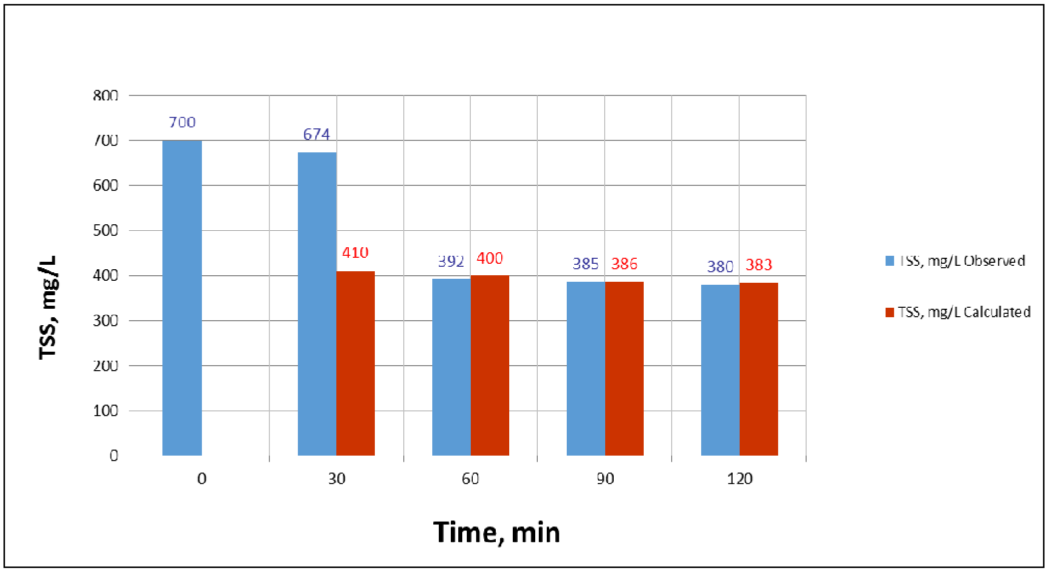


Figure 4.44 TSS removal with 10 mL anaerobically digested sludge

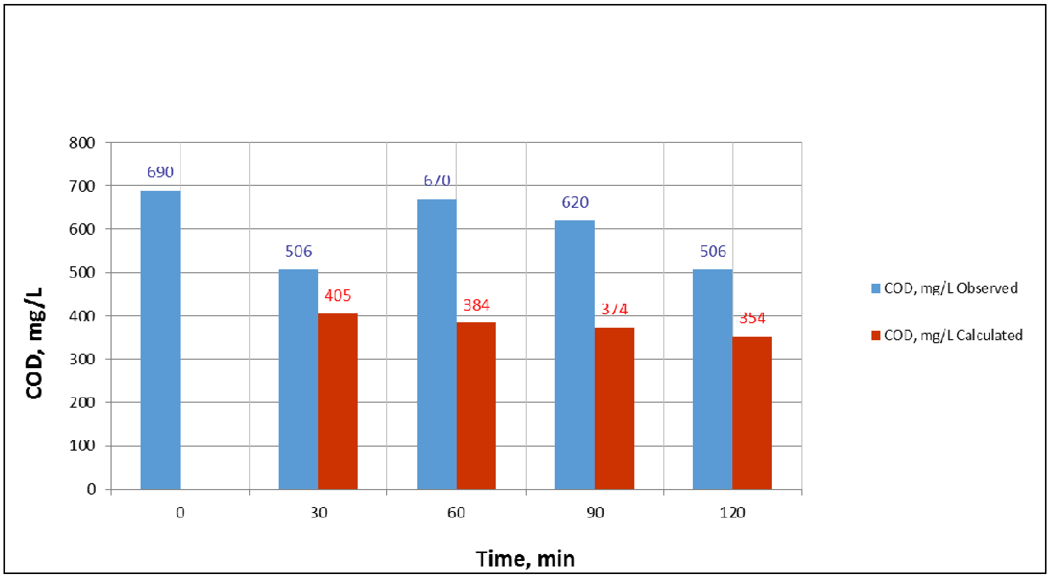


Figure 4.45 COD removal with 10 mL anaerobically digested sludge

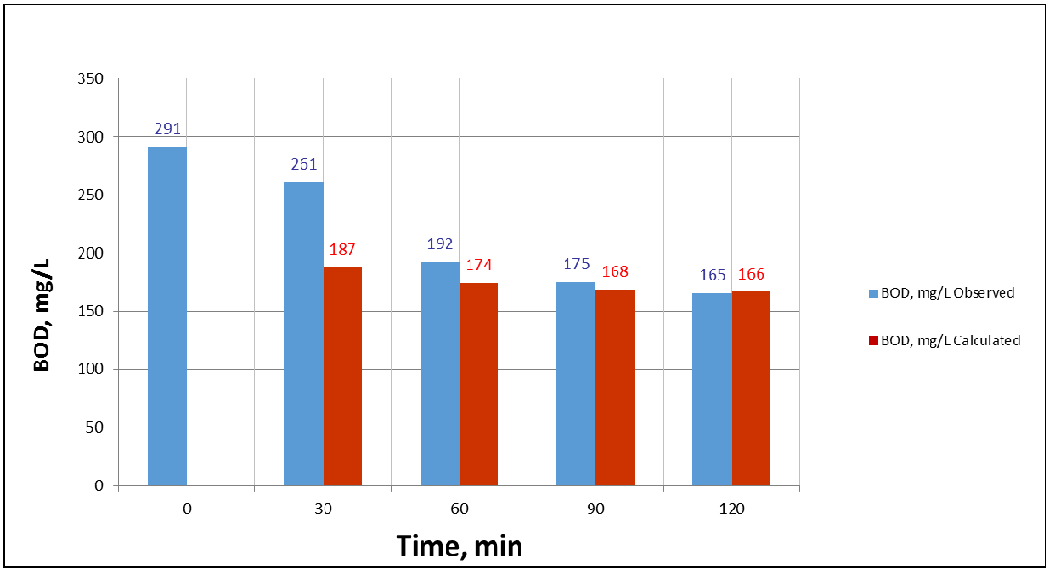


Figure 4.46 BOD removal with 10 mL anaerobically digested sludge

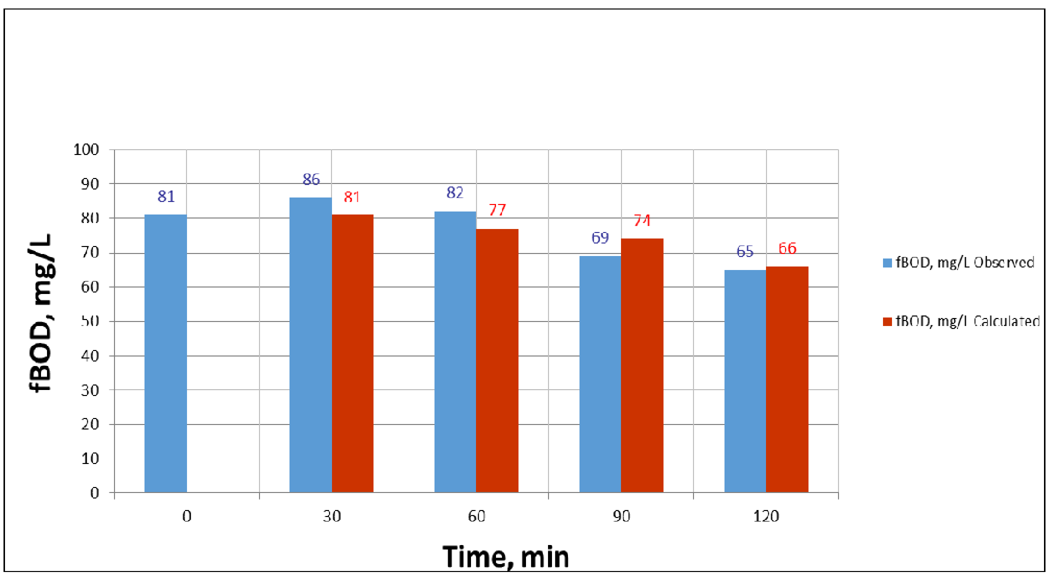


Figure 4.47 fBOD removal with 10 mL anaerobically digested sludge

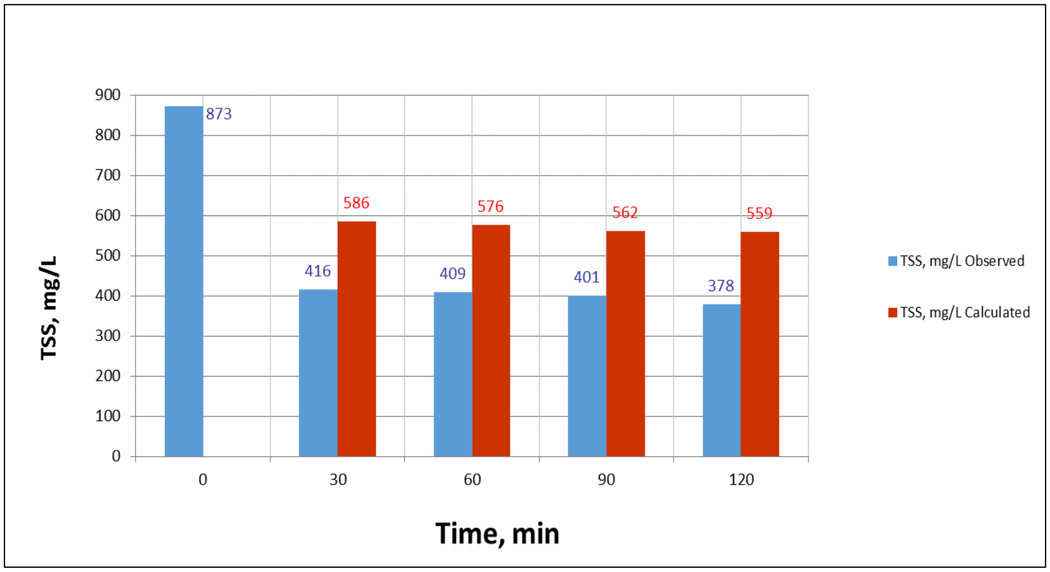


Figure 4.48 TSS removal with 20 mL anaerobically digested sludge

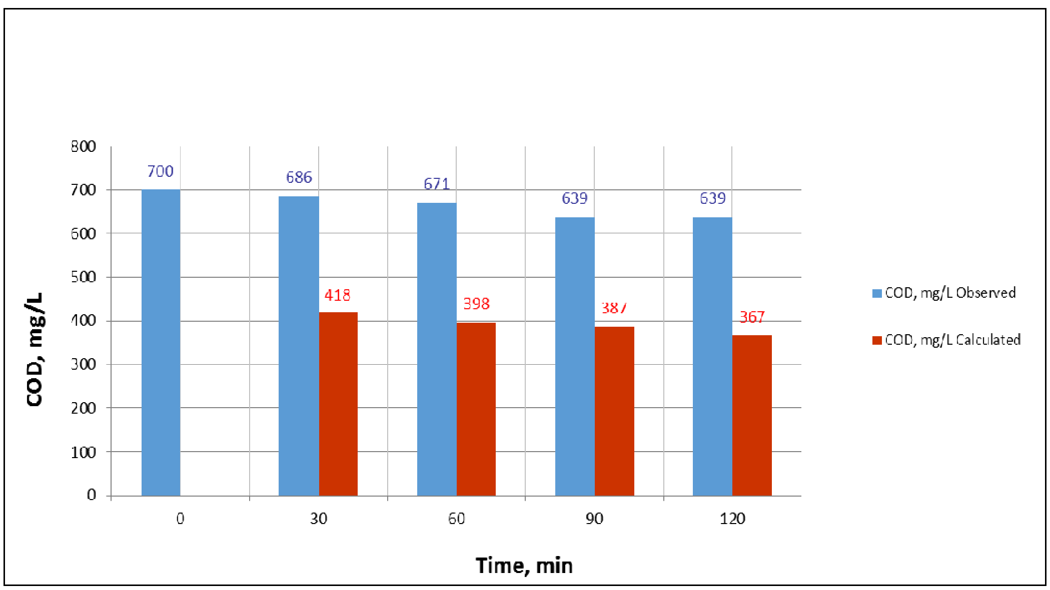


Figure 4.49 COD removal with 20 mL anaerobically digested sludge

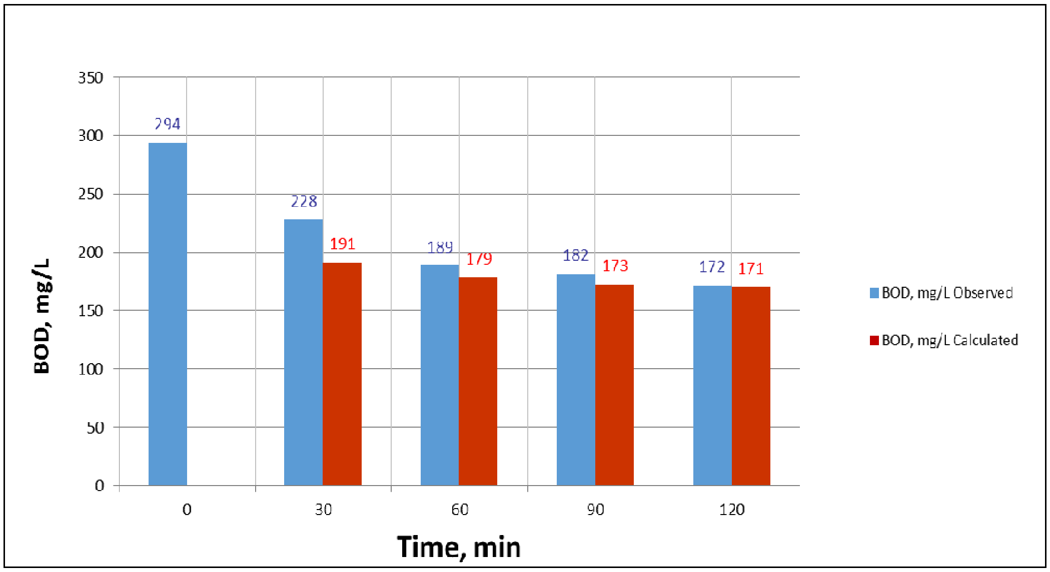


Figure 4.50 BOD removal with 20 mL anaerobically digested sludge

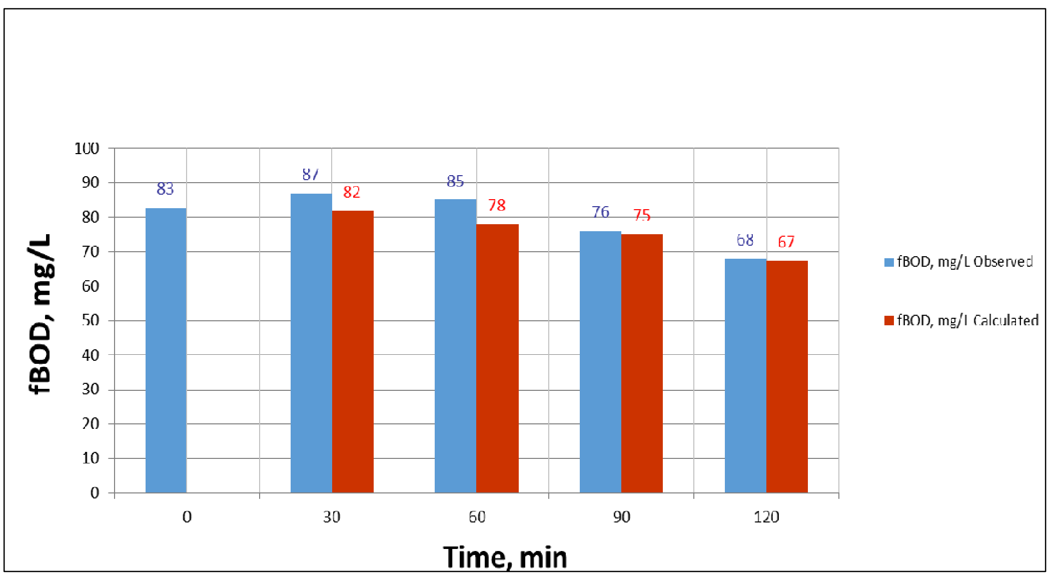


Figure 4.51 fBOD removal with 20 mL anaerobically digested sludge

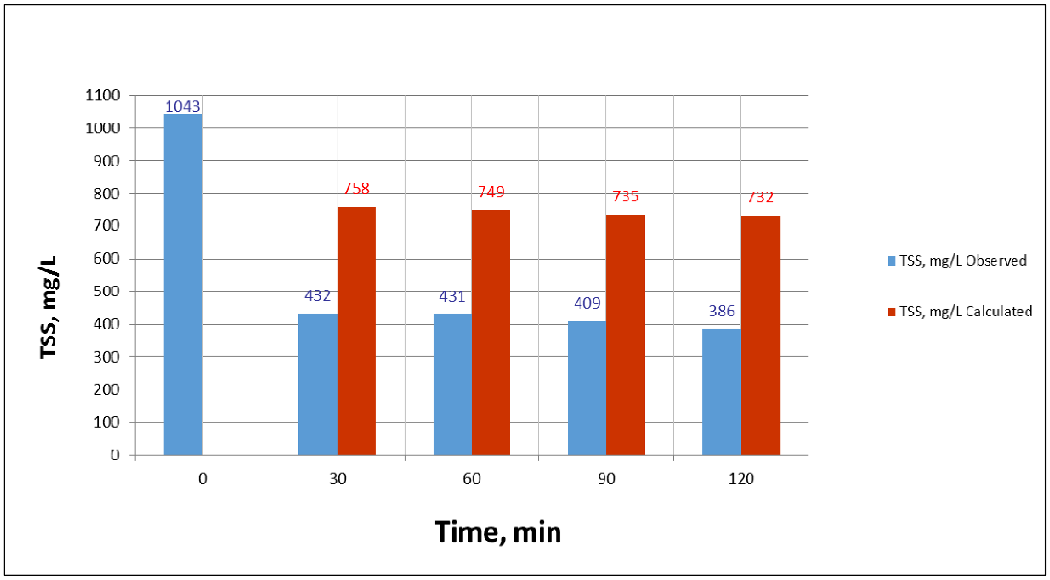


Figure 4.52 TSS removal with 30 mL anaerobically digested sludge

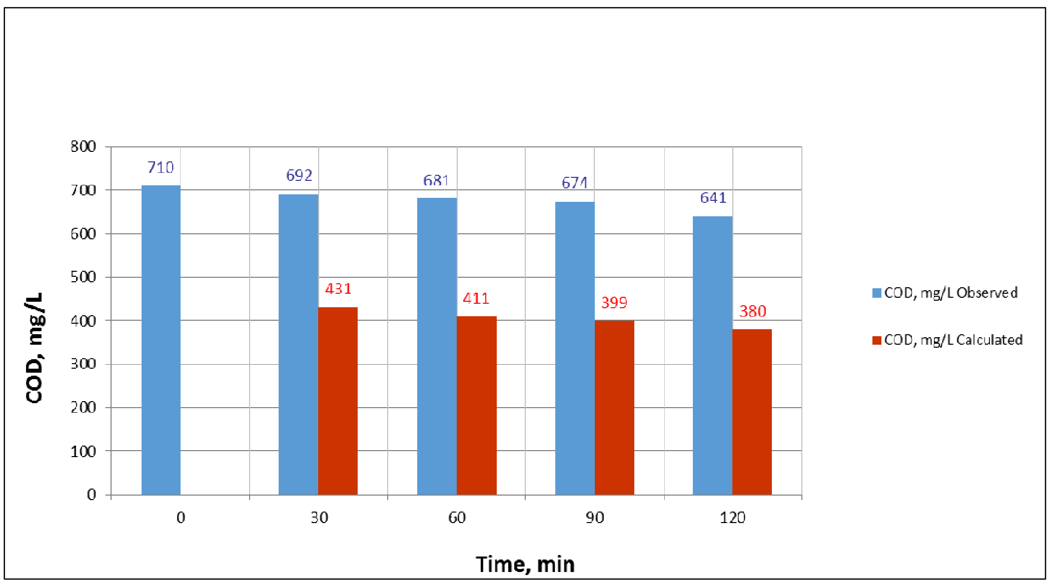


Figure 4.53 COD removal with 30 mL anaerobically digested sludge

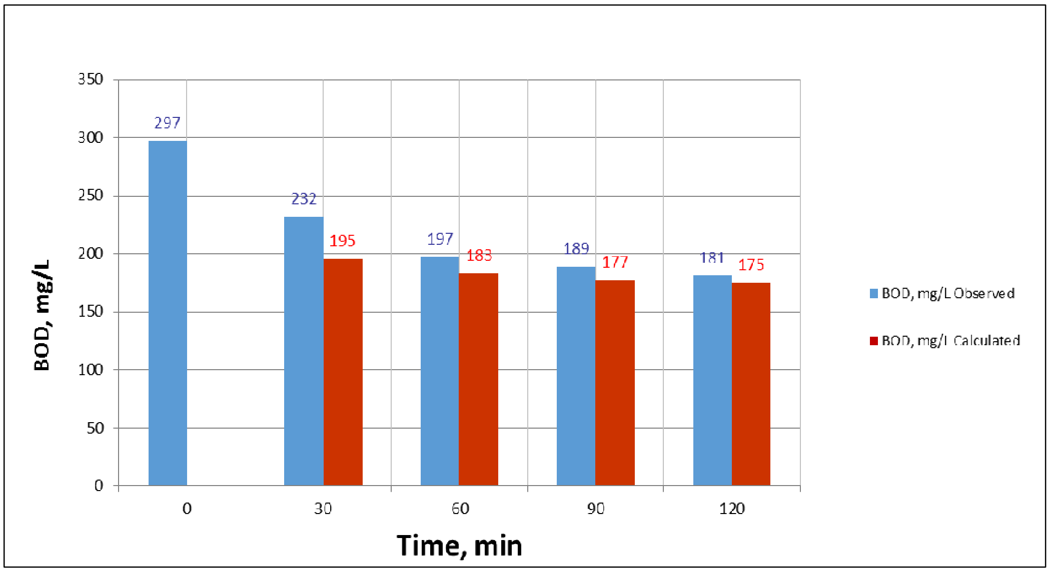


Figure 4.54 BOD removal with 30 mL anaerobically digested sludge

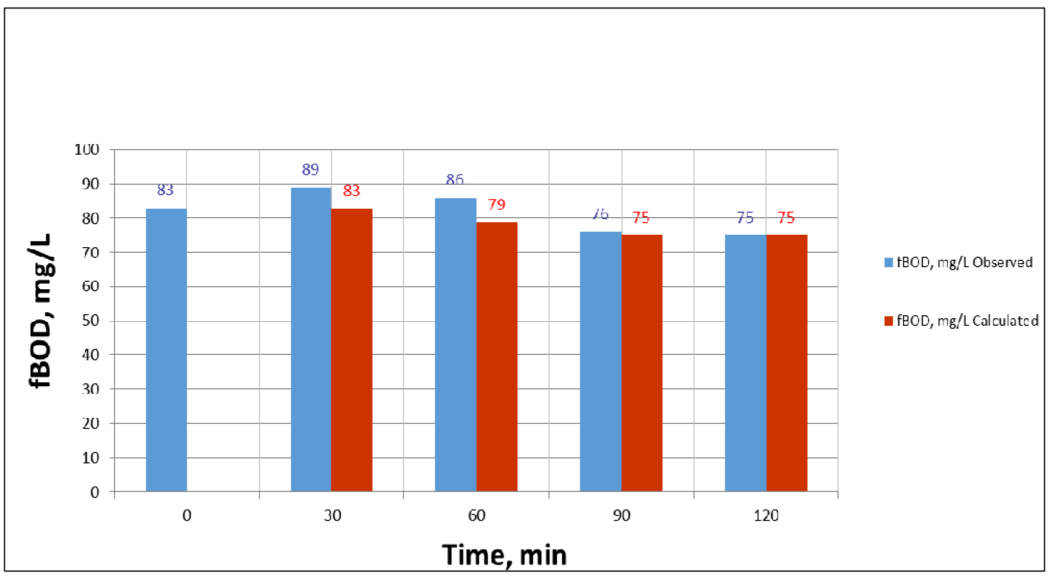


Figure 4.55 fBOD removal with 30 mL anaerobically digested sludge

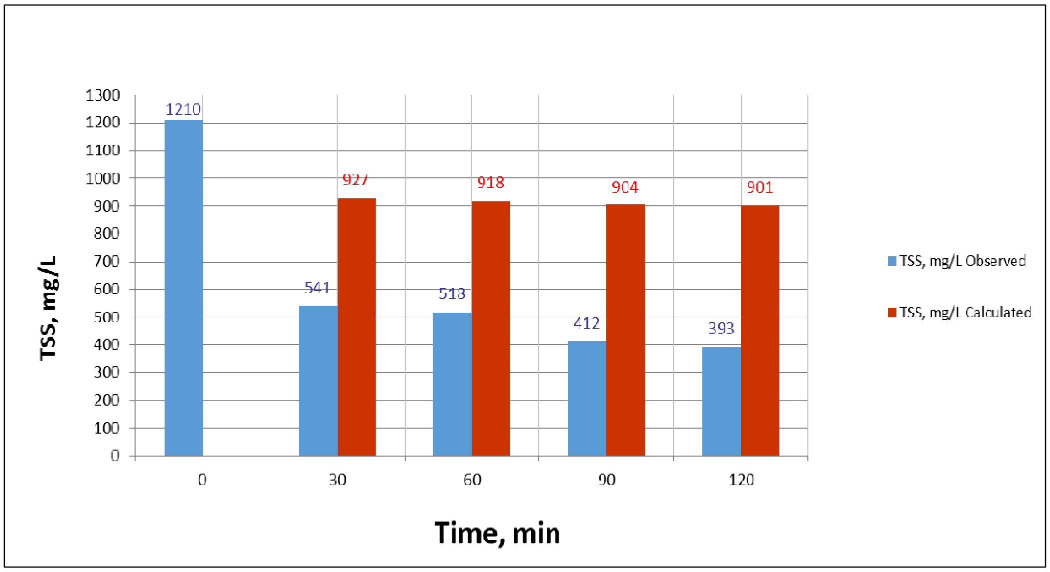


Figure 4.56 TSS removal with 40 mL anaerobically digested sludge

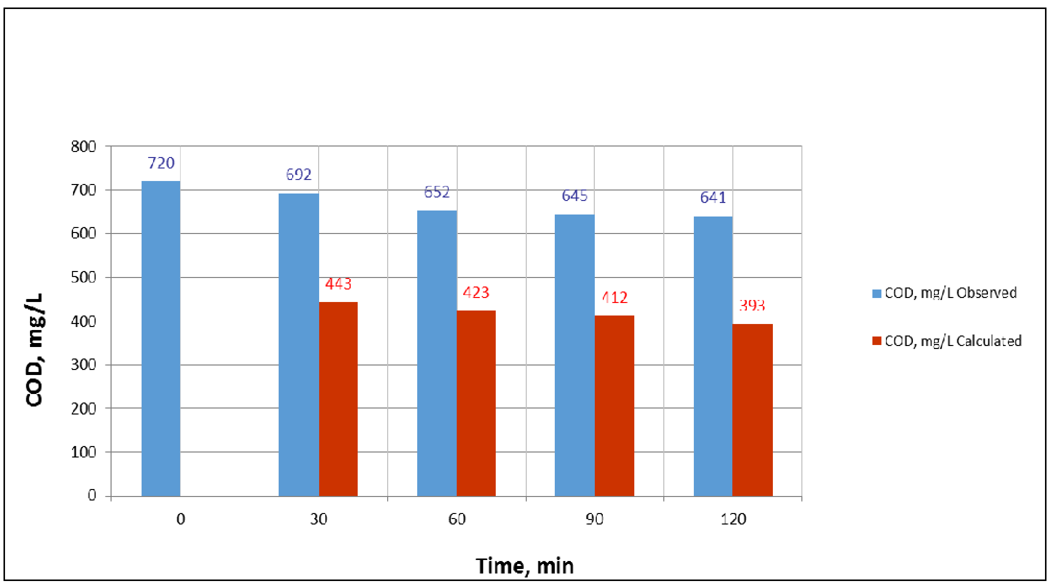


Figure 4.57 COD removal with 40 mL anaerobically digested sludge

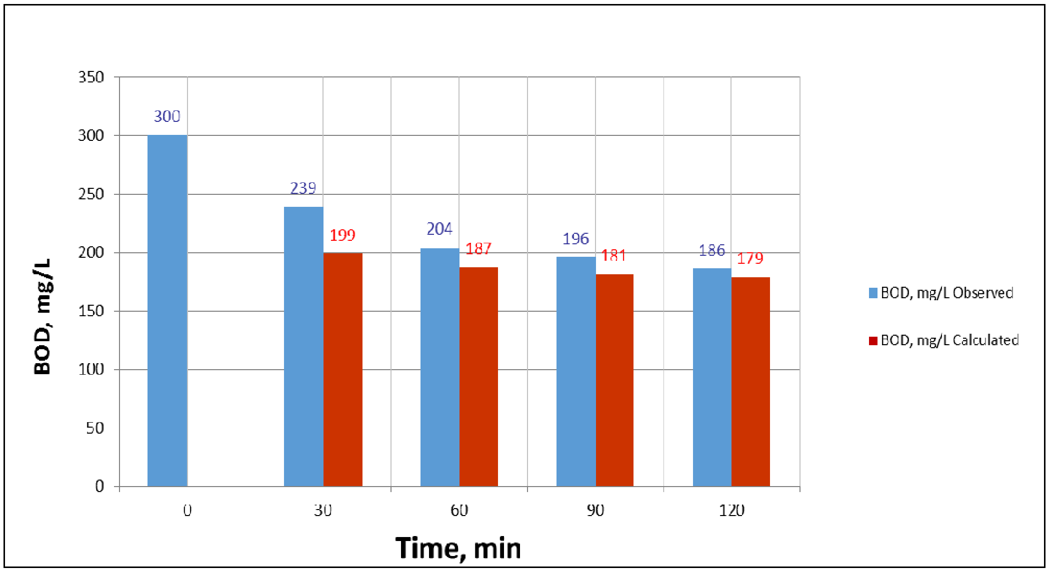


Figure 4.58 BOD removal with 40 mL anaerobically digested sludge

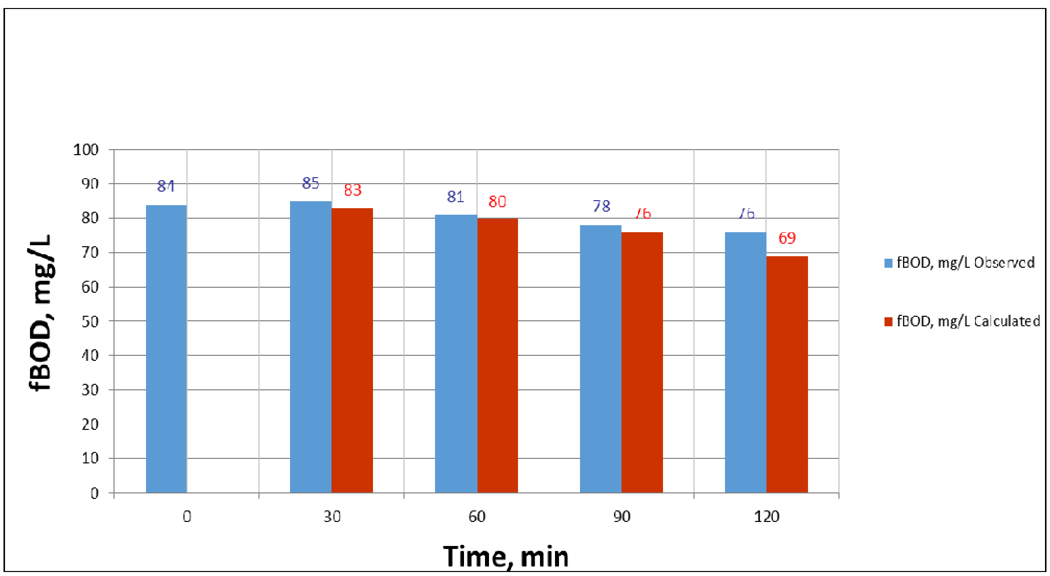


Figure 4.59 fBOD removal with 40 mL anaerobically digested sludge

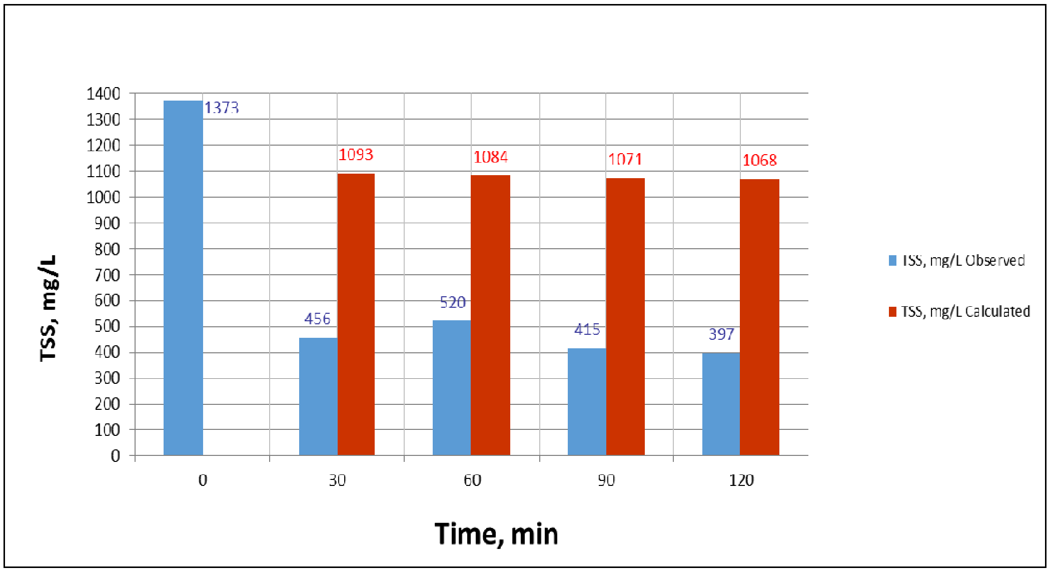


Figure 4.60 TSS removal with 50 mL anaerobically digested sludge

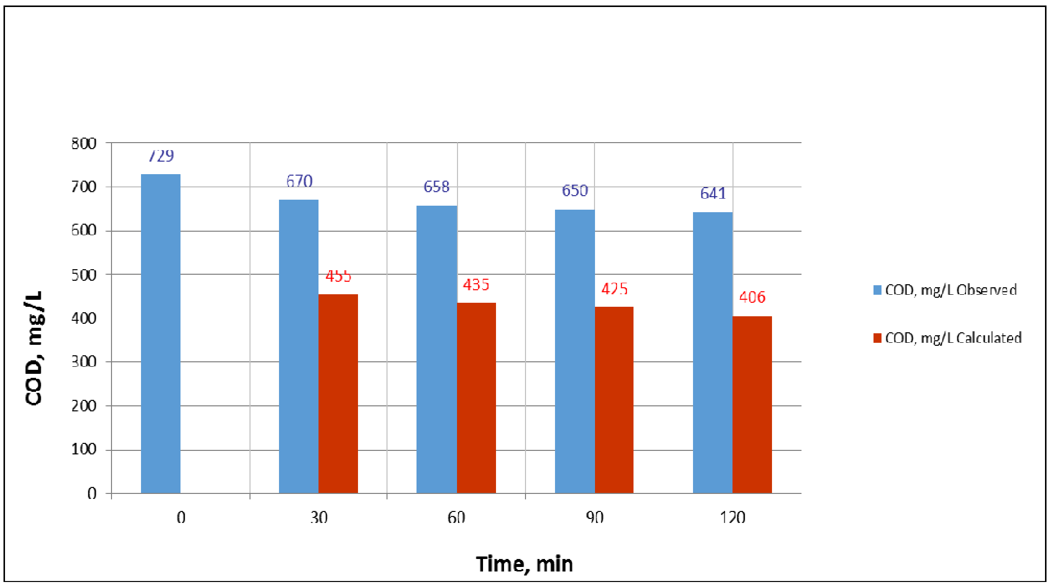


Figure 4.61 COD removal with 50 mL anaerobically digested sludge

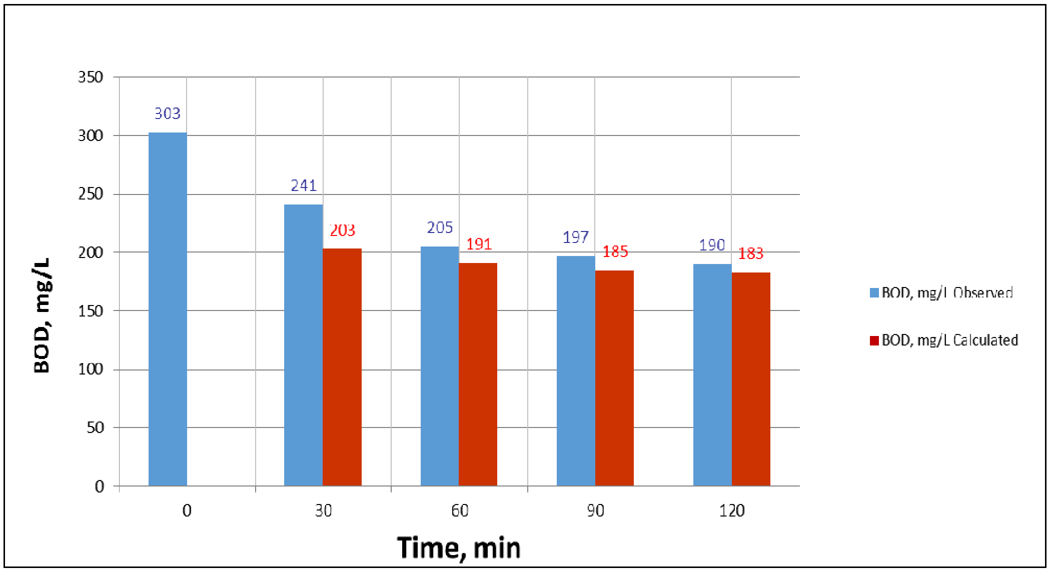


Figure 4.62 BOD removal with 50 mL anaerobically digested sludge

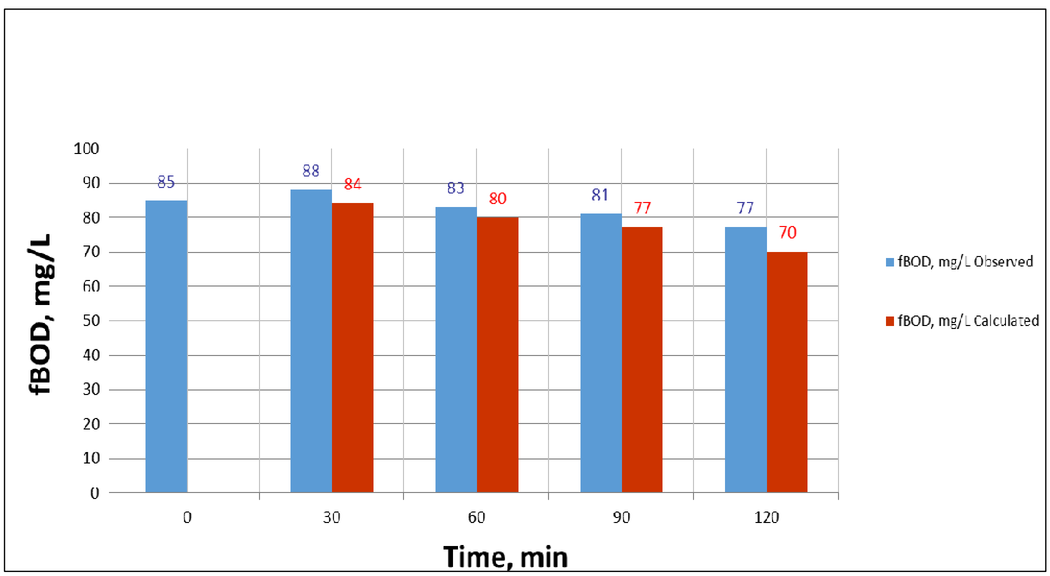


Figure 4.63 fBOD removal with 50 mL anaerobically digested sludge

It can be seen from Figure 4.44 to 4.63 that the observed percentage removal after first 1 h of settling for TSS, COD, BOD and filtered BOD were in the range of 44-62%, 3-10%, 32-36 % and (-)1-3 % respectively. The corresponding calculated removals in these parameters were in the range of 28-57 %, 40-44, 32-40 % and 5-6 % respectively. It was observed that there was only a marginal increase in the TSS removal, but the removal of other parameters suffered significantly. This was probably due to the fact that anaerobically digested sludges do not have good flocculation characteristics and at the same time, they may have some dissolved organic compounds coming from the hydrolysis of microbial cells. Thus, the use of such sludges is not recommended in the suggested modified scheme.

4.2.4. Experiments with addition of secondary excess sludge from STP Brahmapuri

Since the return excess sludge from STP Delawas was not in a good physiological condition due to excessive return flows, it was decided to bring the return excess sludge from STP Brahmapuri, which works on the principles of extended aeration ASP. Experiments were conducted with the addition of this sludge in 10, 20, 30, 40 and 50 mL volumes in 1000 mL of raw sewage of STP Delawas. The settling characteristics of raw sewage and the properties of return sludge are presented in Table 4.7 and 4.8.

Table 4.7 Results of settling of raw sewage sample IV

Duration, min	TSS, mg/L	TSS removal, %	COD, mg/L	COD removal, %	BOD_5, mg/L	BOD_5 removal, %	Filtered BOD_5 , mg/L	Filtered BOD_5 removal, %
0	510	0	654	0	293	0	82	0
30	236	54%	390	40%	184	37%	80	2%
60	216	58%	371	43%	170	42%	76	7%
90	209	59%	357	45%	166	43%	73	11%
120	198	61%	338	48%	164	44%	65	21%

Table 4.8 Characteristic of return sludge of 27 MLD (extended aeration process)

Parameters	Return sludge of 27 MLD STP Brahampuri (extended aeration)
TSS, mg/L	24936
COD, mg/L	3104
BOD_5, mg/L	590
Filtered BOD_5, mg/L	145

The results obtained with the addition of 10, 20, 30, 40 and 50 mL return sludge of 27 MLD capacity STP, Brahmapuri based on extended aeration process in 1000 mL raw sewage sample IV are shown in Figures 4.64-4.83.

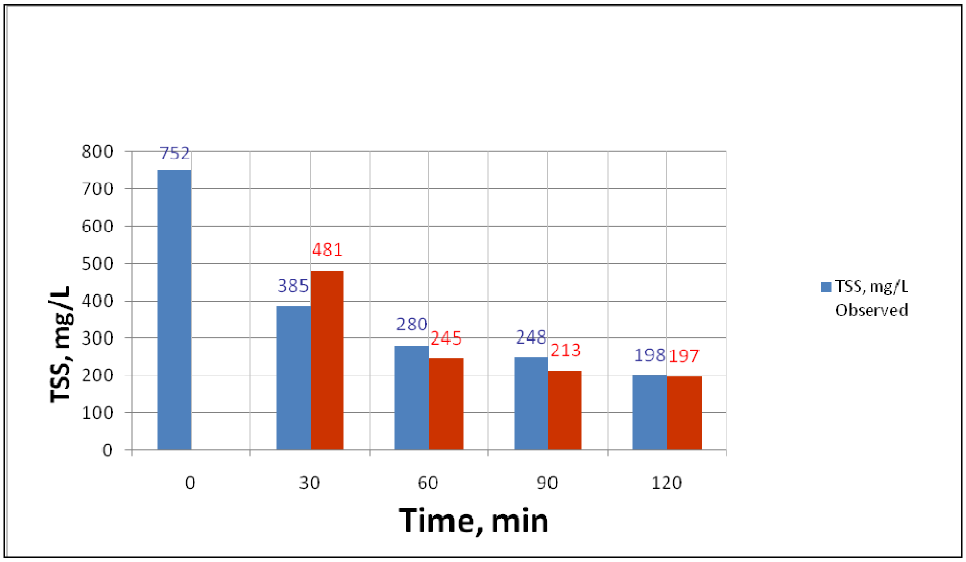


Figure 4.64 TSS removal with 10 mL return sludge (extended aeration)

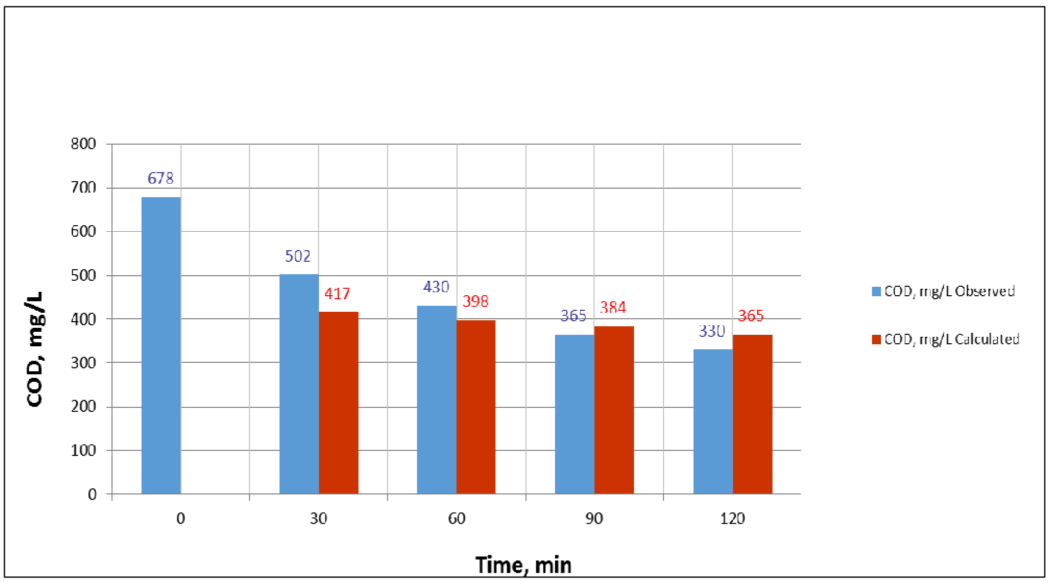


Figure 4.65 COD removal with 10 mL return sludge (extended aeration)

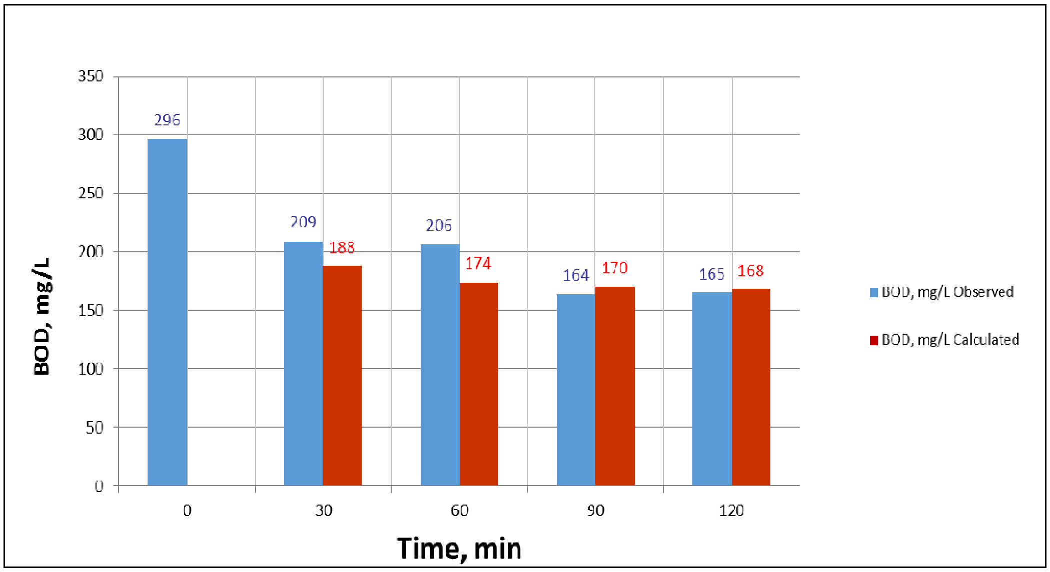


Figure 4.66 BOD removal with 10 mL return sludge (extended aeration)

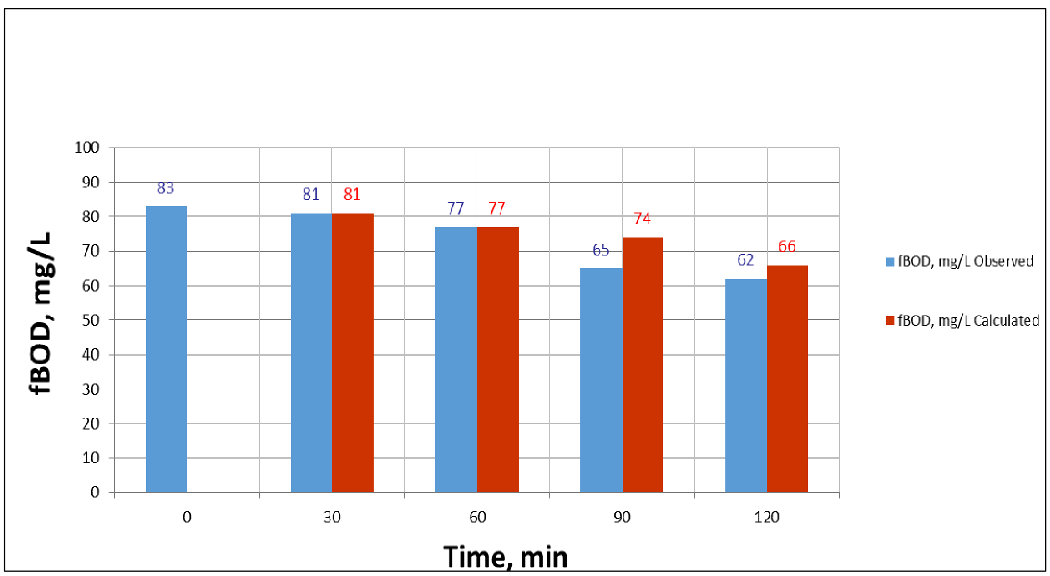


Figure 4.67 fBOD removal with 10 mL return sludge (extended aeration)

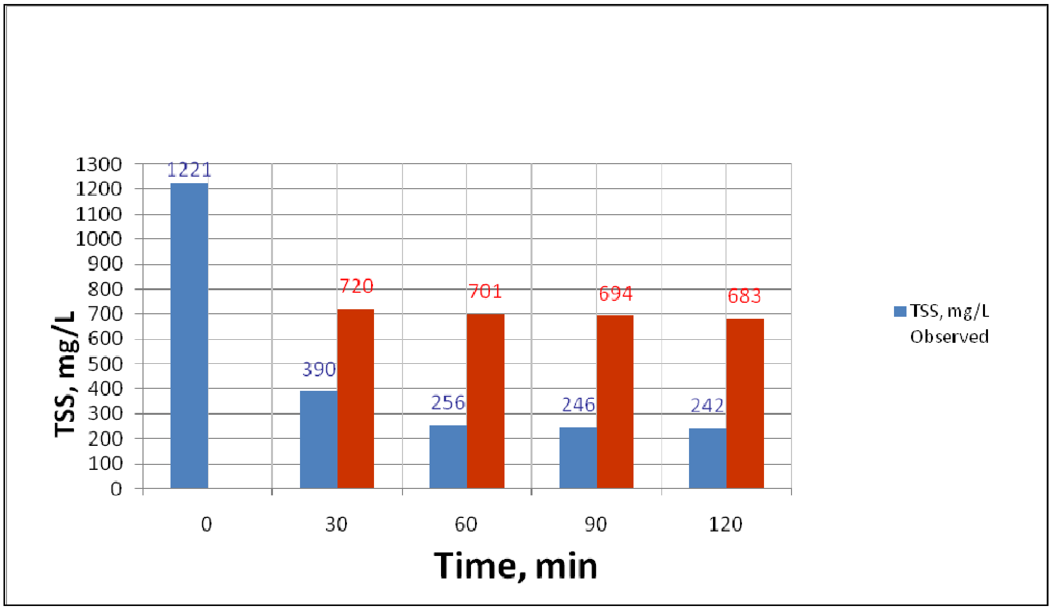


Figure 4.68 TSS removal with 20 mL return sludge (extended aeration)

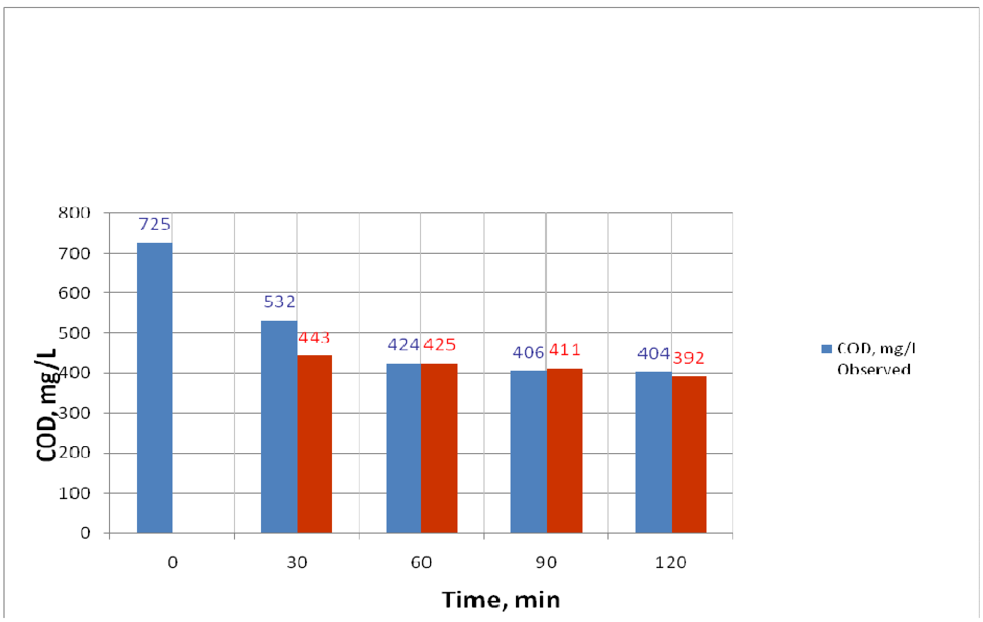


Figure 4.69 COD removal with 20 mL return sludge (extended aeration)

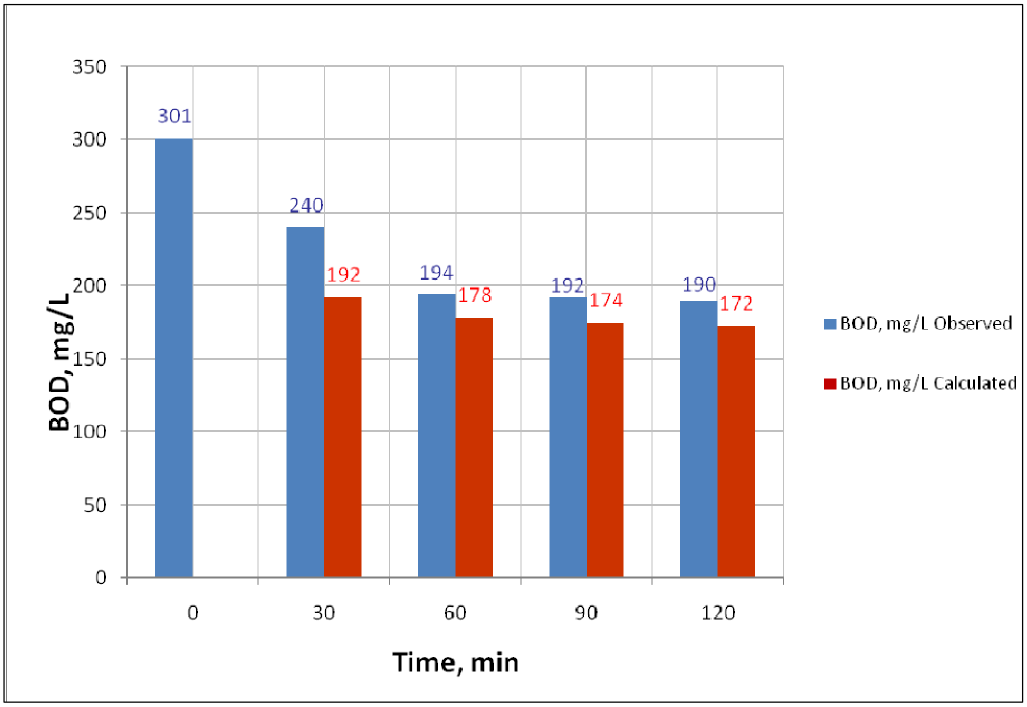


Figure 4.70 BOD removal with 20 mL return sludge (extended aeration)

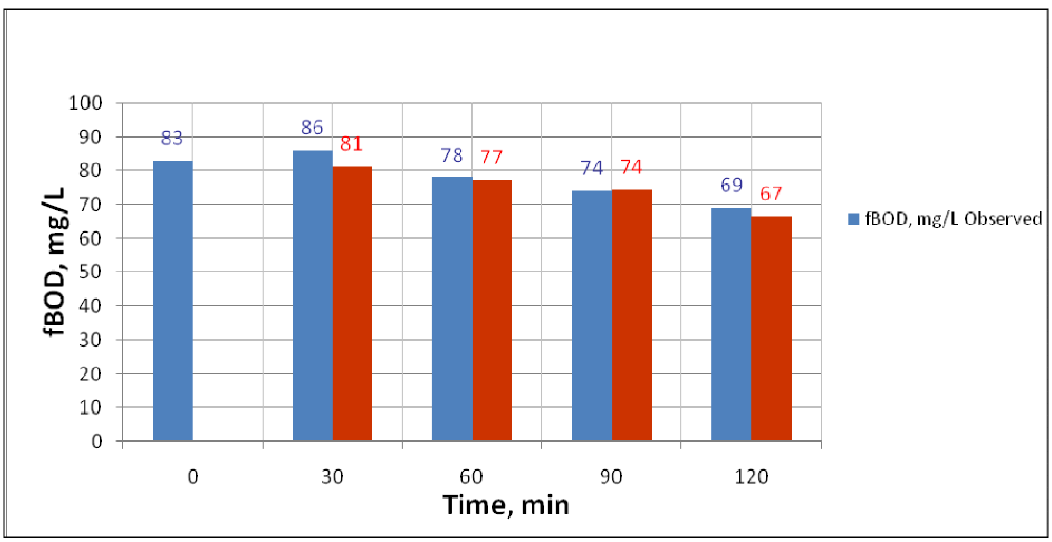


Figure 4.71 fBOD removal with 20 mL return sludge (extended aeration)

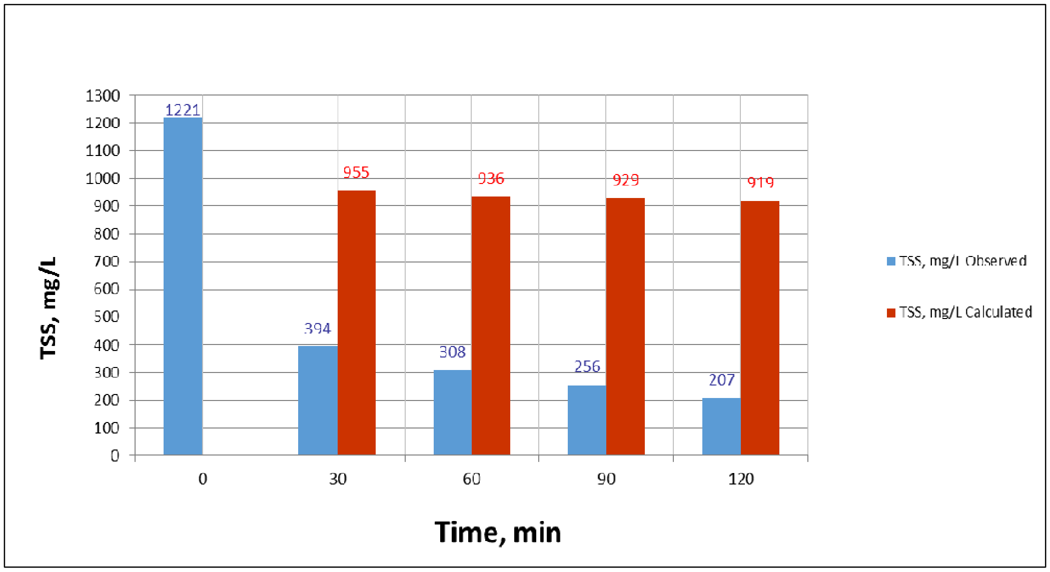


Figure 4.72 TSS removal with 30 mL return sludge (extended aeration)

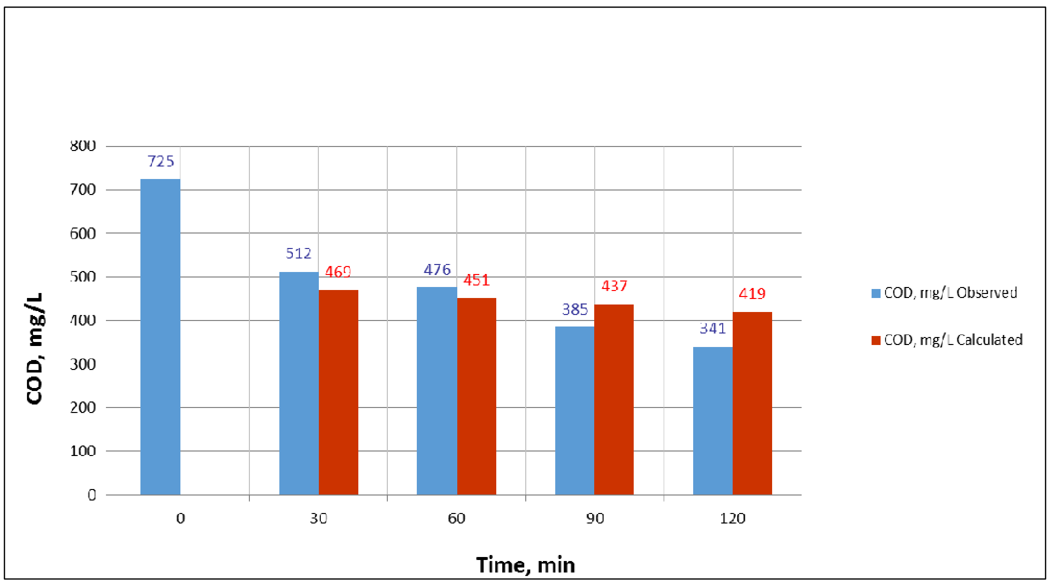


Figure 4.73 COD removal with 30 mL return sludge (extended aeration)

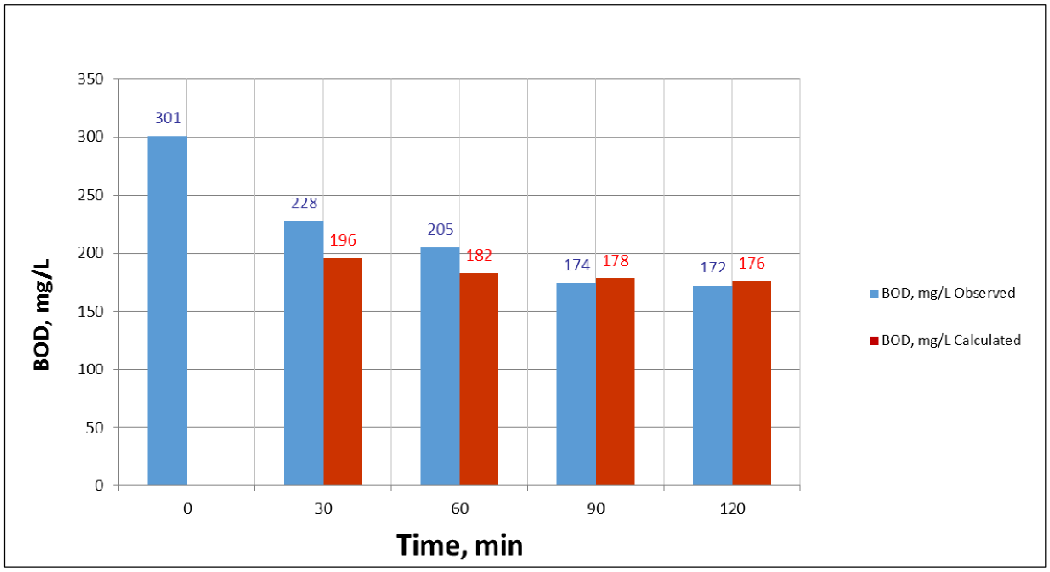


Figure 4.74 BOD removal with 30 mL return sludge (extended aeration)

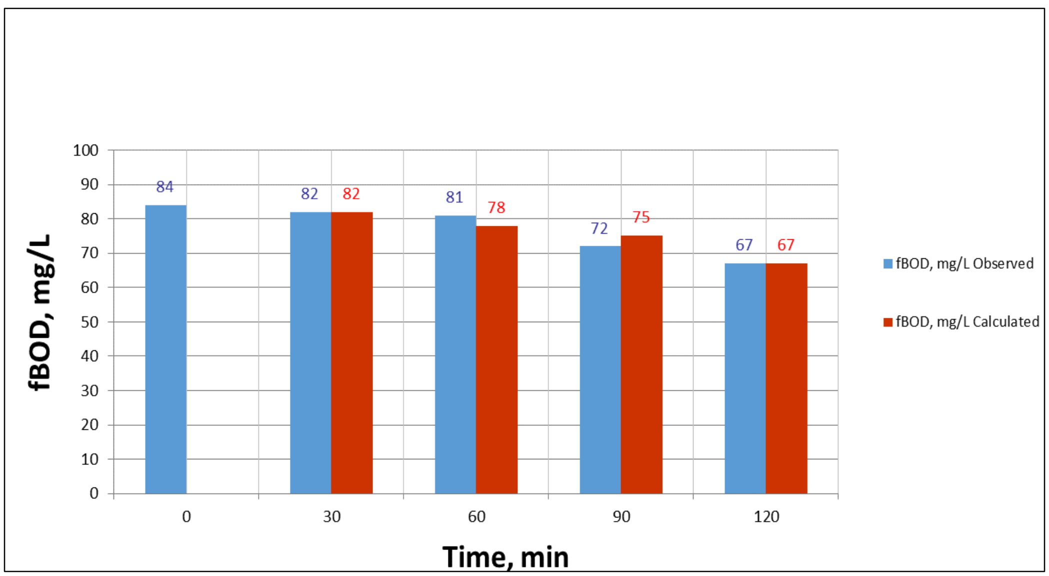


Figure 4.75 fBOD removal with 30 mL return sludge (extended aeration)

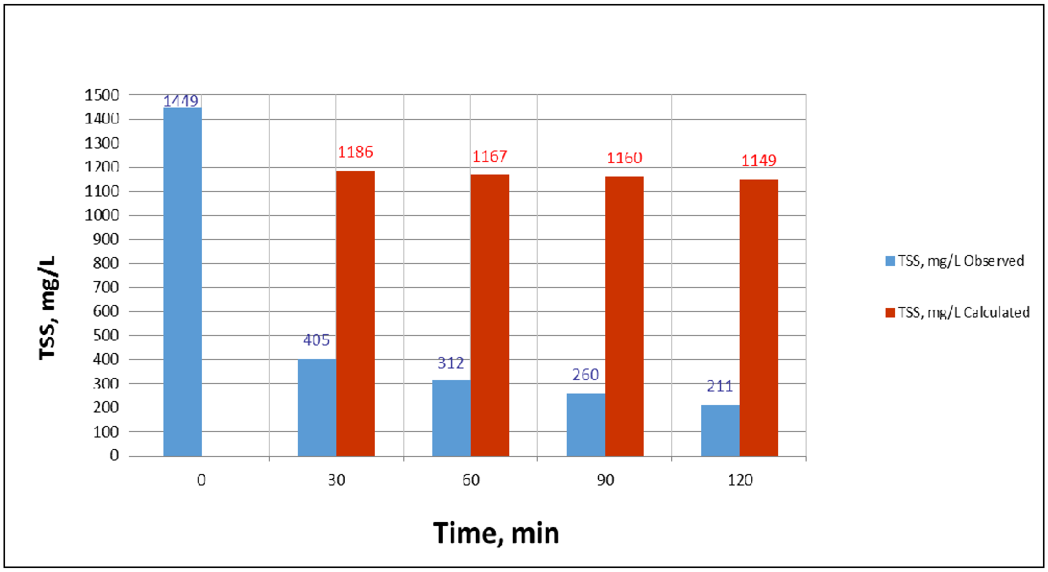


Figure 4.76 TSS removal with 40 mL return sludge (extended aeration)

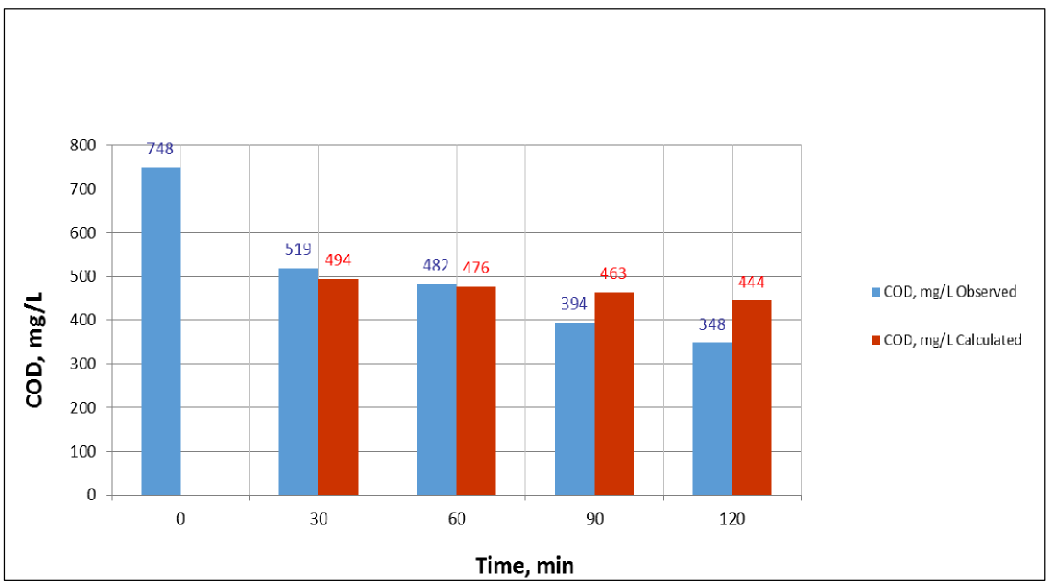


Figure 4.77 COD removal with 40 mL return sludge (extended aeration)

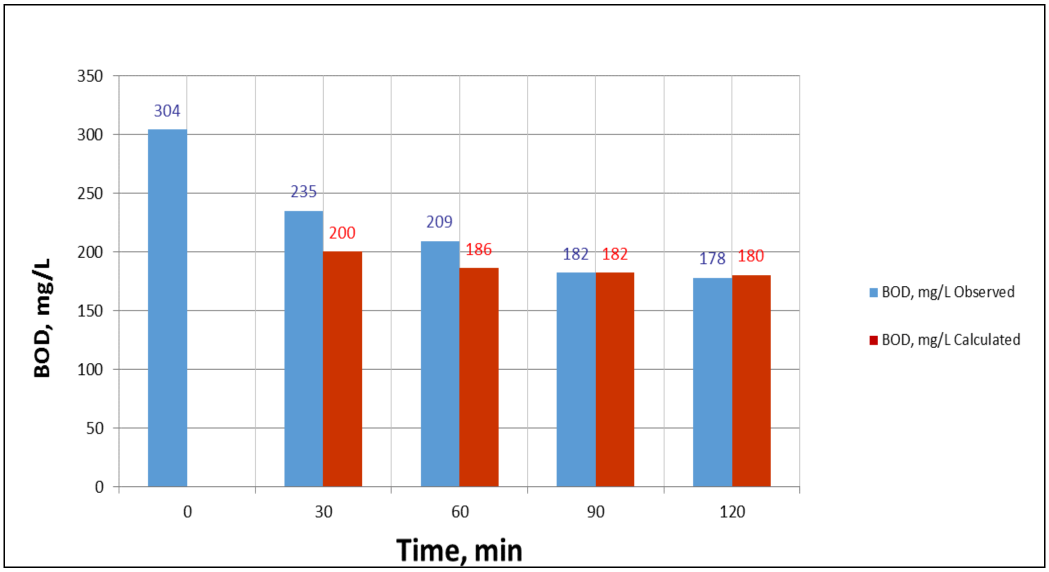


Figure 4.78 BOD removal with 40 mL return sludge (extended aeration)

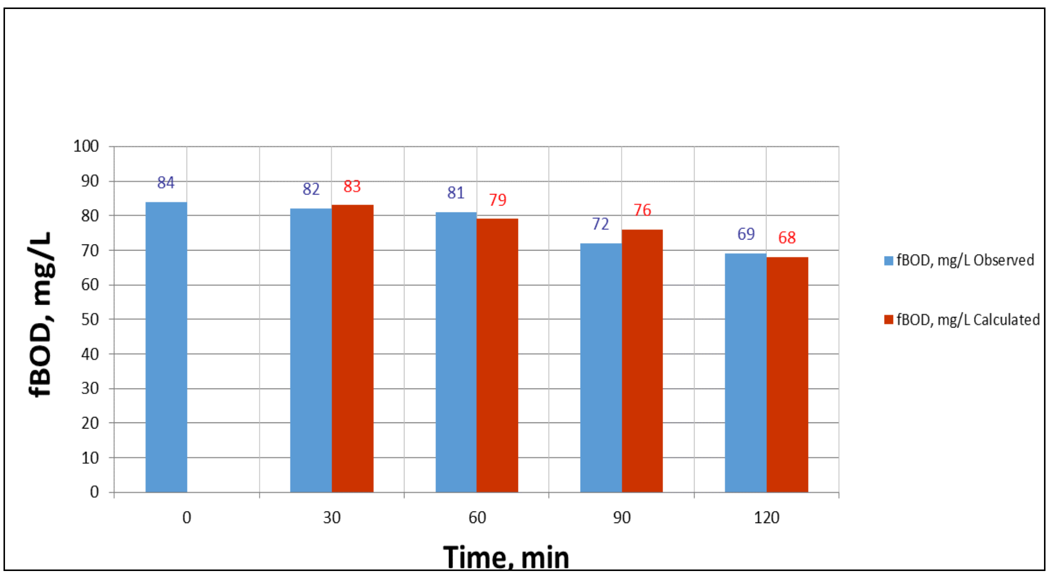


Figure 4.79 fBOD removal with 40 mL return sludge (extended aeration)

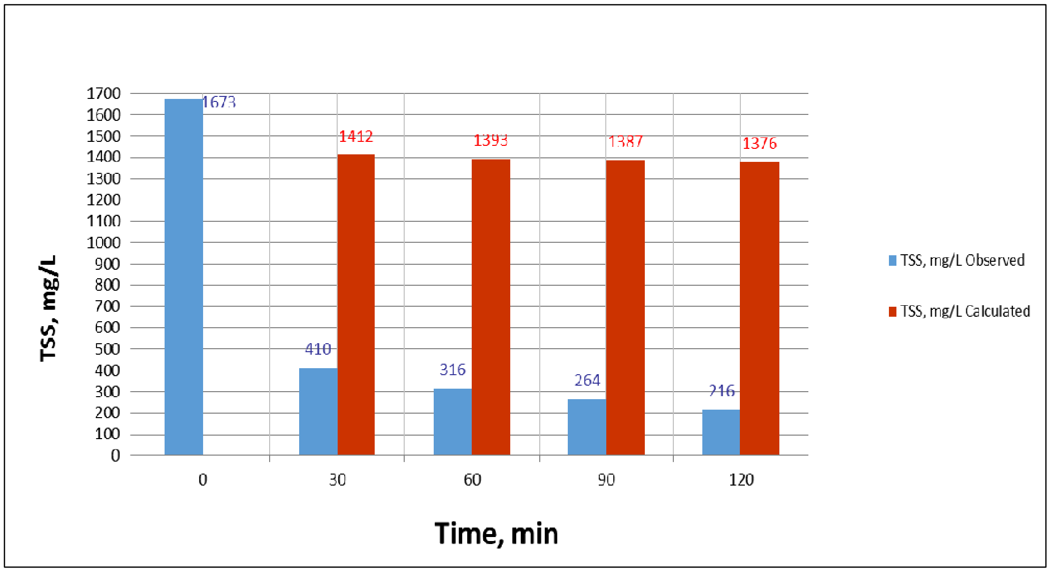


Figure 4.80 TSS removal with 50 mL return sludge (extended aeration)

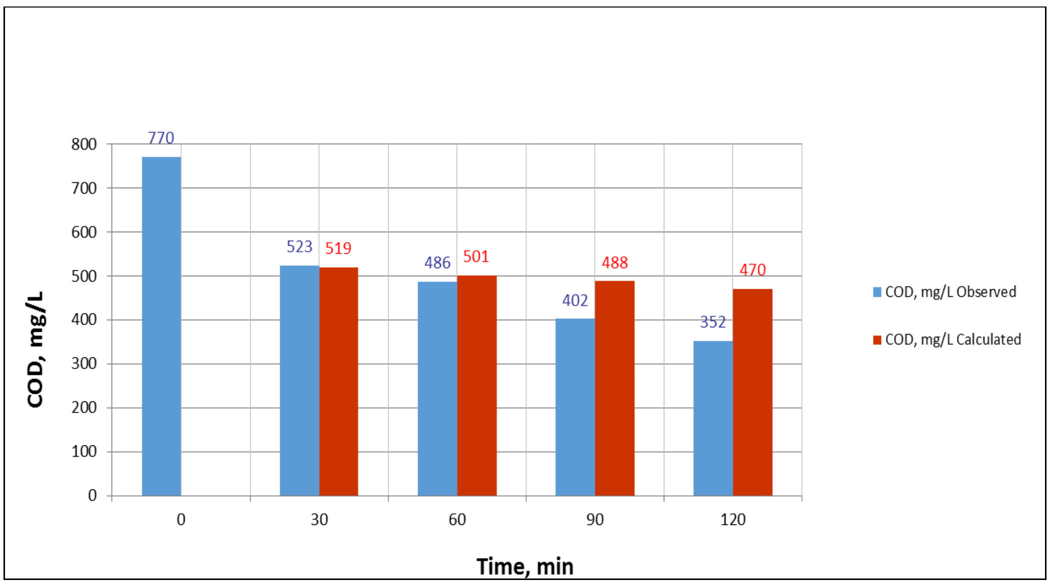


Figure 4.81 COD removal with 50 mL return sludge (extended aeration)

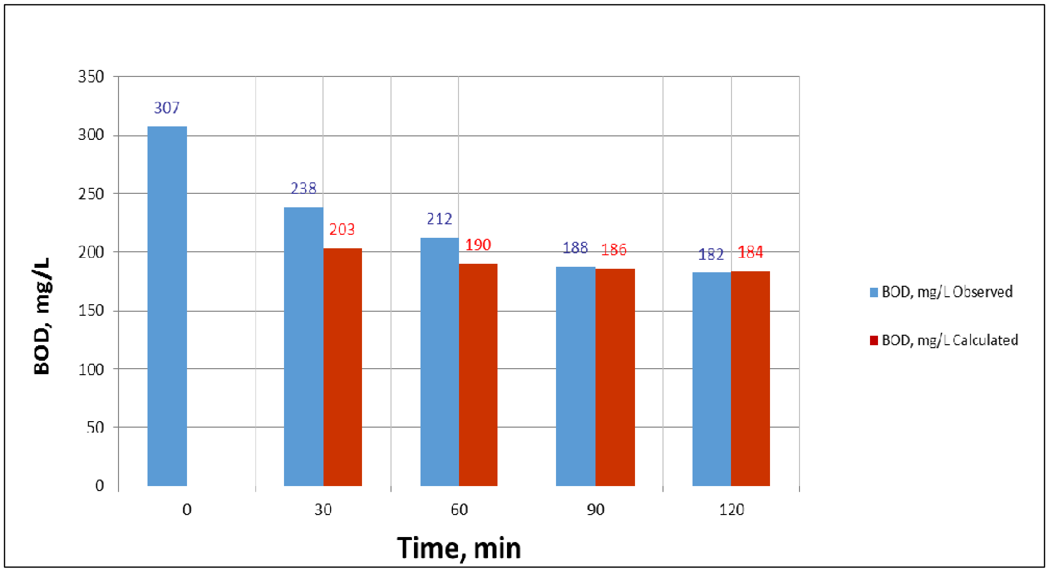


Figure 4.82 BOD removal with 50 mL return sludge (extended aeration)

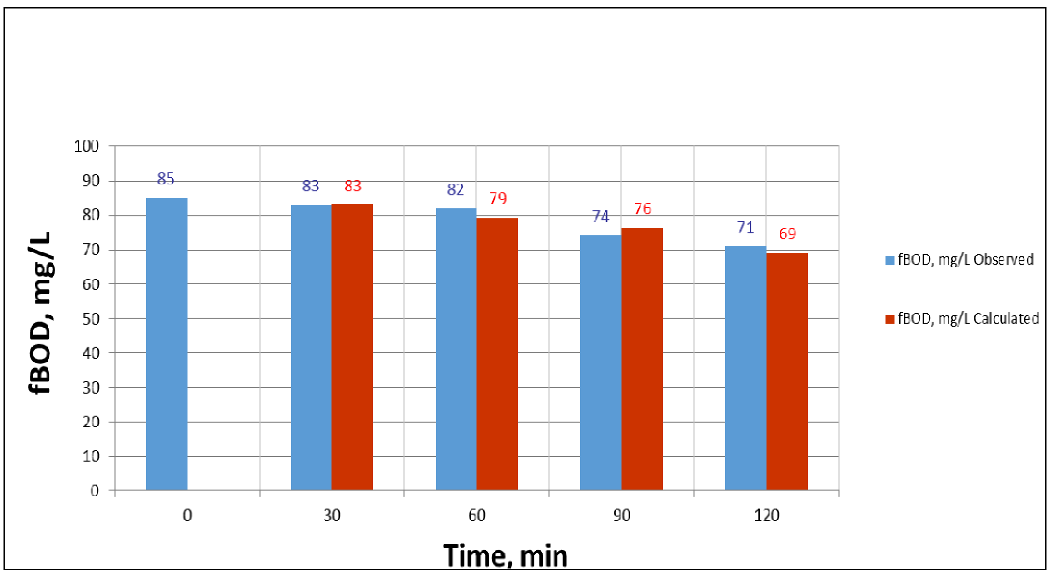


Figure 4.83 fBOD removal with 50 mL return sludge (extended aeration)

It can be seen Figure 4.64 to4.83 that the observed removal of TSS, COD, BOD_5 and filtered BOD_5 in first hour was 63 %, 37%, 30 % and 7% respectively indicating that first hour is more important in the removal of TSS, COD and BOD_5. In the second hour the additional removal in TSS, COD, BOD_5 and filtered BOD_5 observed were 9%, 10%, 14% and 18 % respectively. It indicated that the second hour was more effective in the removal of BOD and filtered BOD (soluble fraction) probably due to the absorption into the cells. The maximum removal in TSS and COD of 87 and 54 % was observed with the addition of 50 mL after 2 h settling. Maximum removals of 44 and 25 % in BOD & fBOD were observed with addition of 10 mL after 2 h settling. The calculated values of removal in TSS, COD, BOD and fBOD were 41% with 10 mL sludge, 41% with 30 mL of sludge, 43 and 20% with 10 mL of sludge addition respectively. Thus, the observed values were highly favorable in terms of removal of TSS and COD, while marginal benefits were obtained for BOD & filtered BOD removals. Addition of 10 mL of this sludge provided optimum results.

4.2.5. Settling experiments with aerobically digested sludge from STP Brahmapuri

STP Brahmapuri is the only plant in India that has a provision of aerobic digestion of sludge. Settling experiments were conducted with 10, 20, 30, 40, and 50 mL of this sludge added to 1000 mL of raw sewage from STP Delawas. The settling characteristics of raw sewage sample V and the properties of aerobically digested sludge are represented in Tables 4.9 and 4.10.

Table 4.9 Results of settling of raw sewage sample V

Duration, min	TSS, mg/L	TSS removal, %	COD, mg/L	COD removal, %	BOD_5, mg/L	BOD_5 removal, %	Filtered BOD_5, mg/L	Filtered BOD_5 removal, %
0	514	0	692	0	287	0	82	0
30	236	54%	396	43%	181	37%	78	5%
60	214	58%	372	46%	167	42%	75	9%
90	207	60%	354	49%	163	43%	72	12%
120	201	61%	338	51%	162	44%	64	22%

Table 4.4 Characteristic of aerobically digested sludge of 27 MLD STP Brahampuri (extended aeration process)

Parameters	Aerobically digested sludge of 27 MLD STP Brahampuri
TSS, mg/L	29900
COD, mg/L	3200
BOD_5, mg/L	535
Filtered BOD, mg/L	130

The results of settling analysis of these experiments are shown in Figures 4.84- 4.103

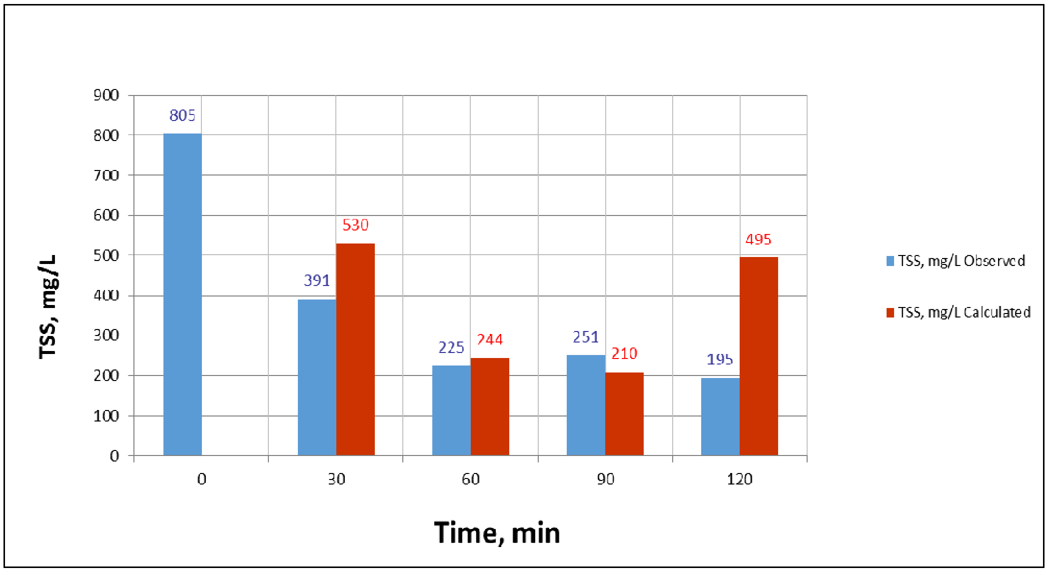


Figure 4.84 TSS removal with 10 mL aerobically digested sludge

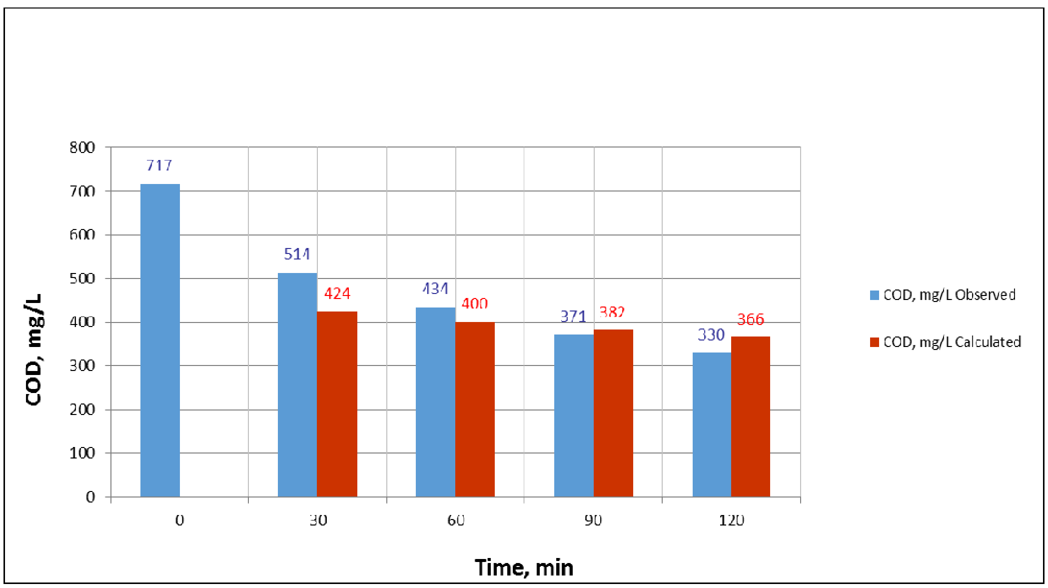


Figure 4.85 COD removal with 10 mL aerobically digested sludge

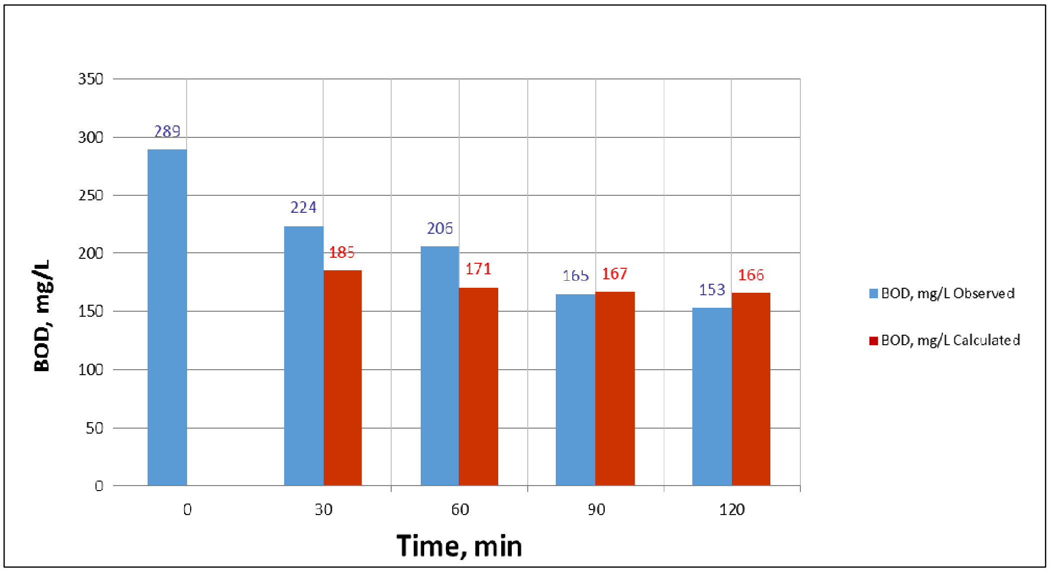


Figure 4.86 BOD removal with 10 mL aerobically digested sludge

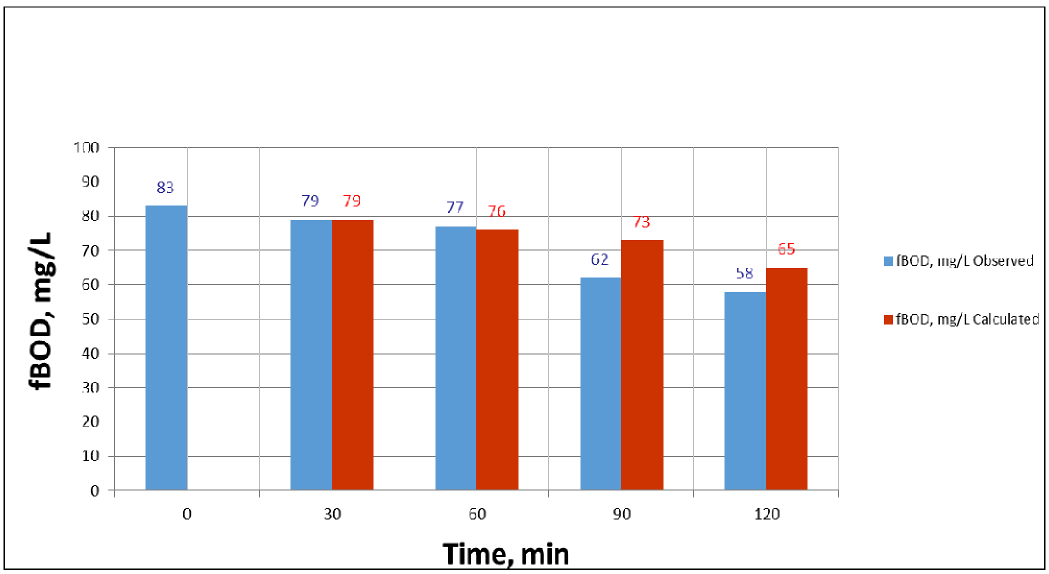


Figure 4.87 fBOD removal with 10 mL aerobically digested sludge

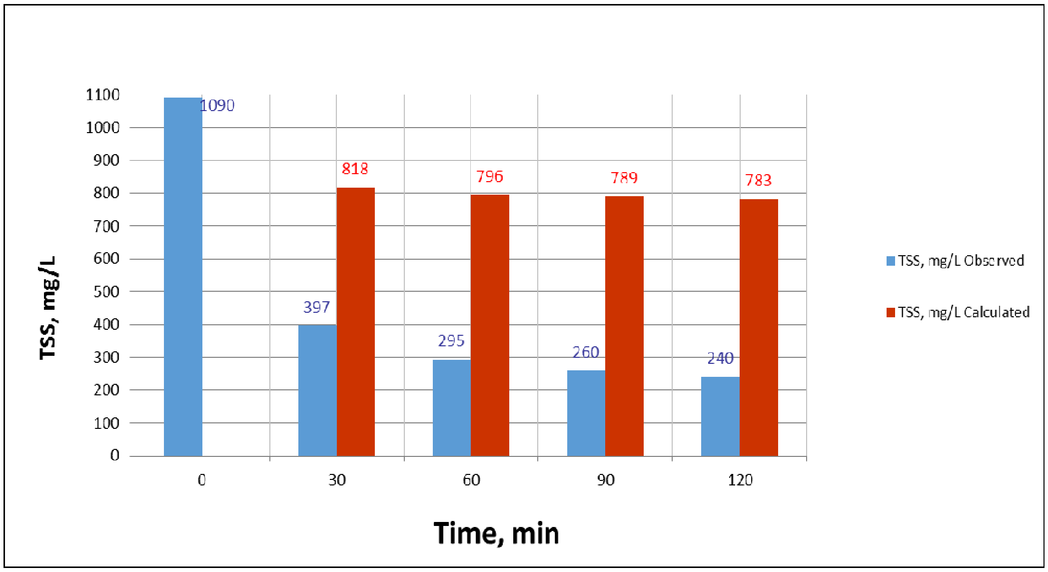


Figure 4.88 TSS removal with 20 mL aerobically digested sludge

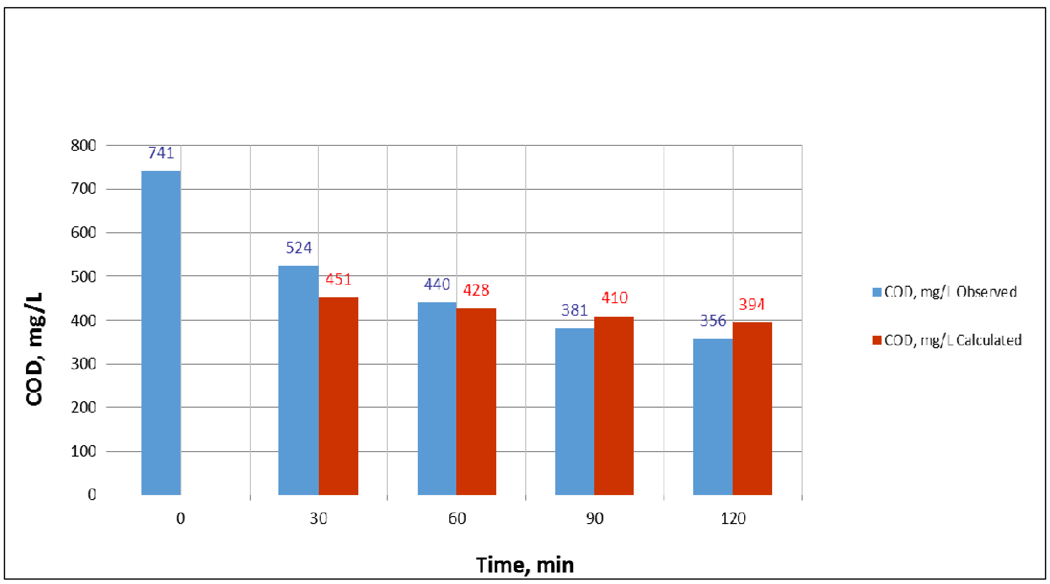


Figure 4.89 COD removal with 20 mL aerobically digested sludge

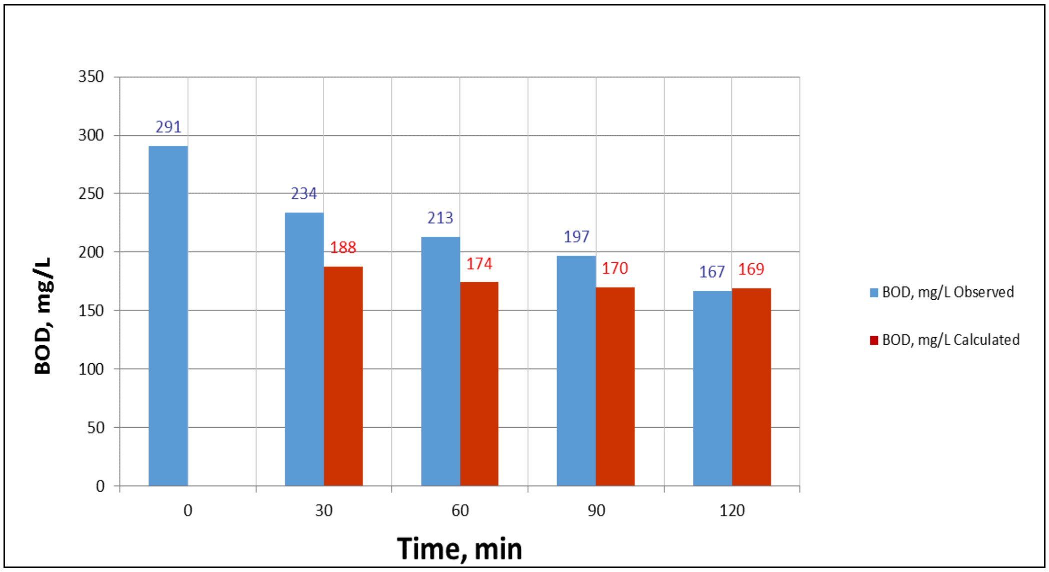


Figure 4.90 BOD removal with 20 mL aerobically digested sludge

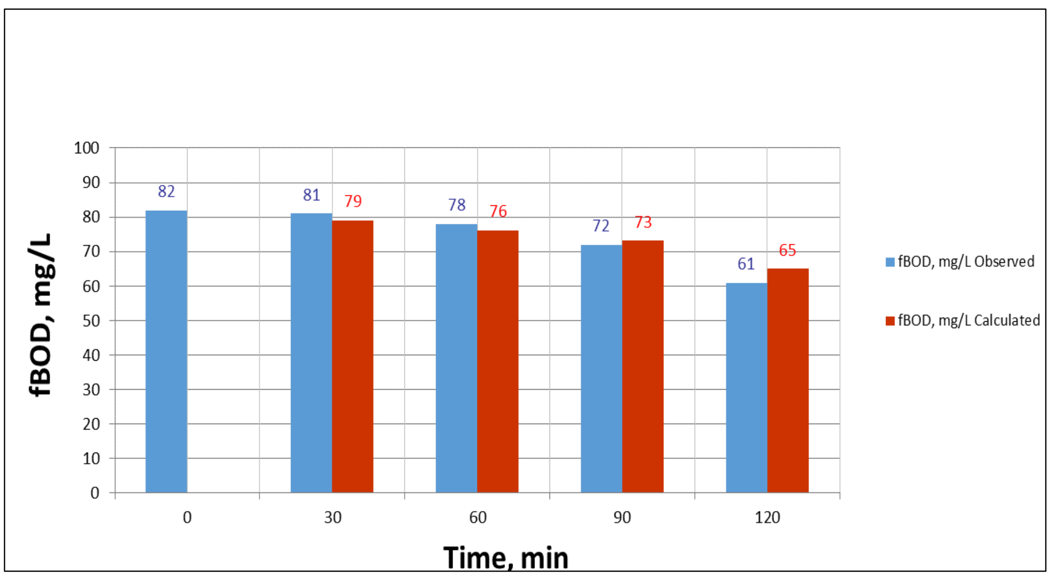


Figure 4.91 fBOD removal with 20 mL aerobically digested sludge

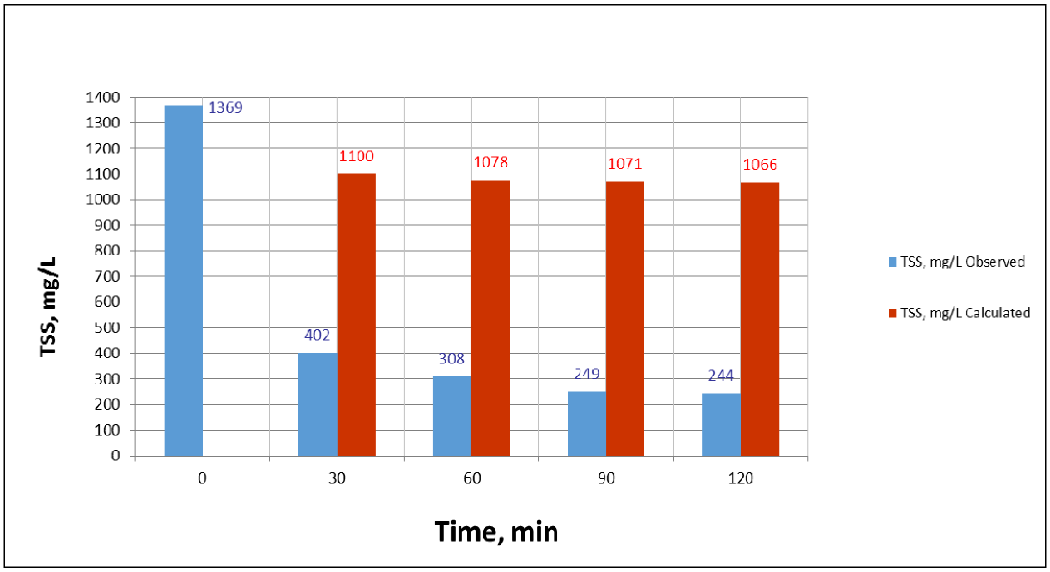


Figure 4.92 TSS removal with 30 mL aerobically digested sludge

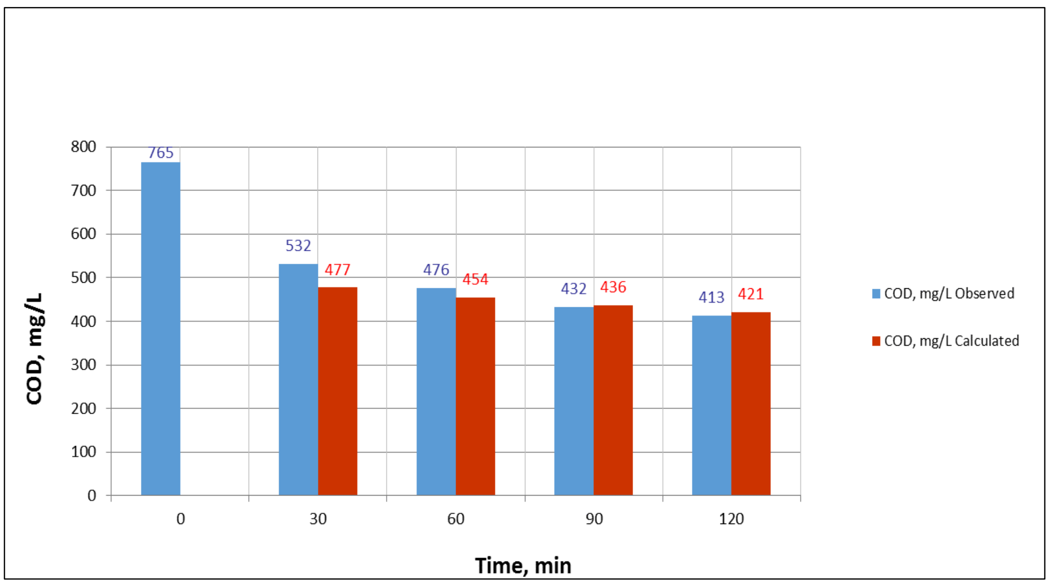


Figure 4.93 COD removal with 30 mL aerobically digested sludge

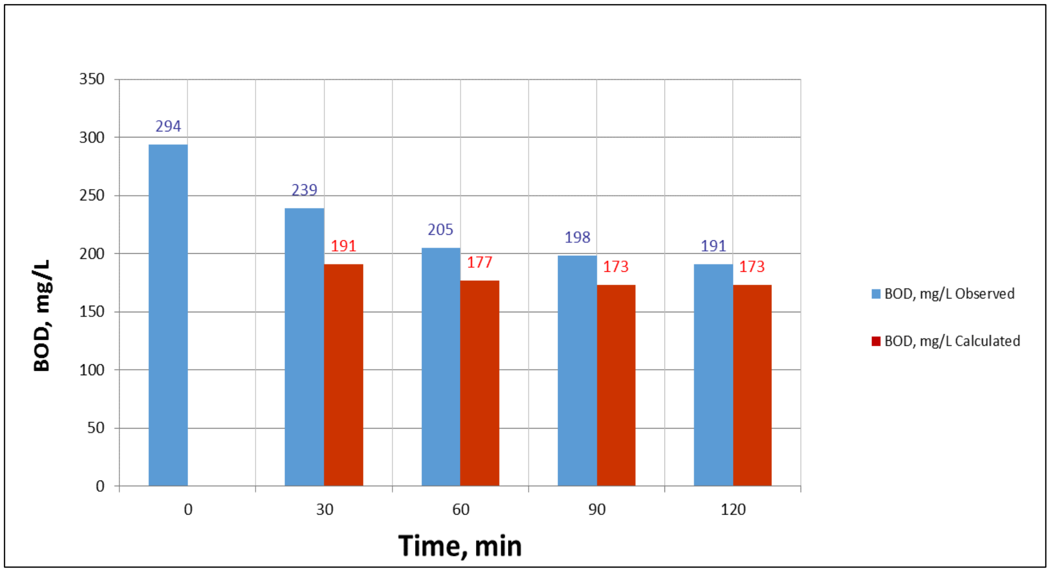


Figure 4.94 BOD removal with 30 mL aerobically digested sludge

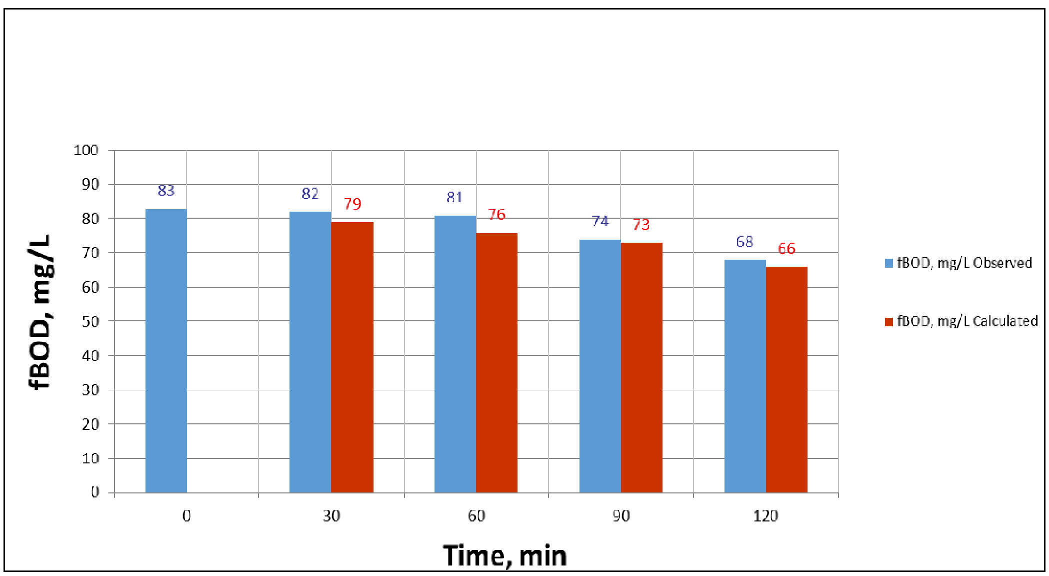


Figure 4.95 fBOD removal with 30 mL aerobically digested sludge

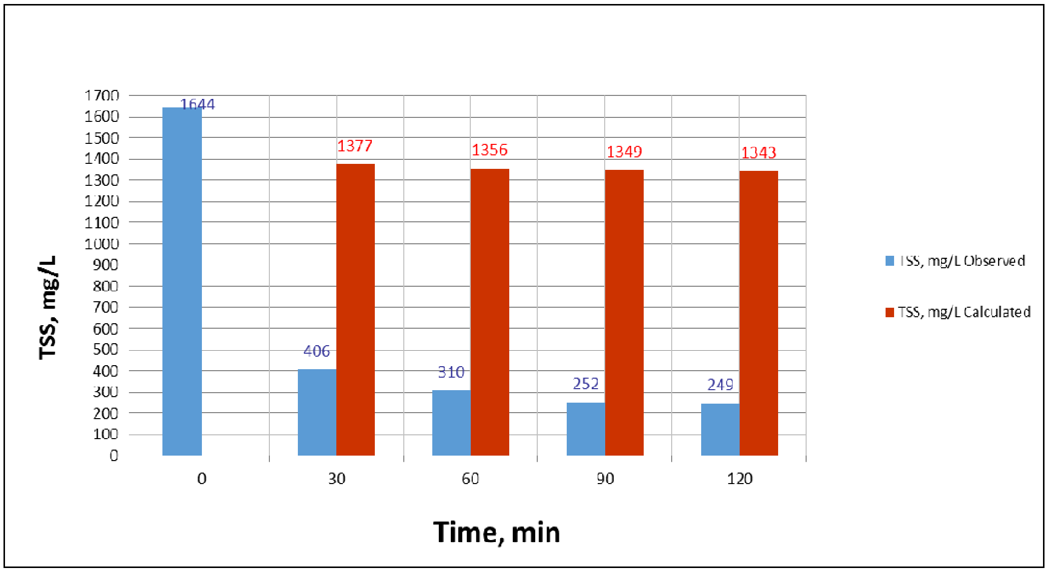


Figure 4.96 TSS removal with 40 mL aerobically digested sludge

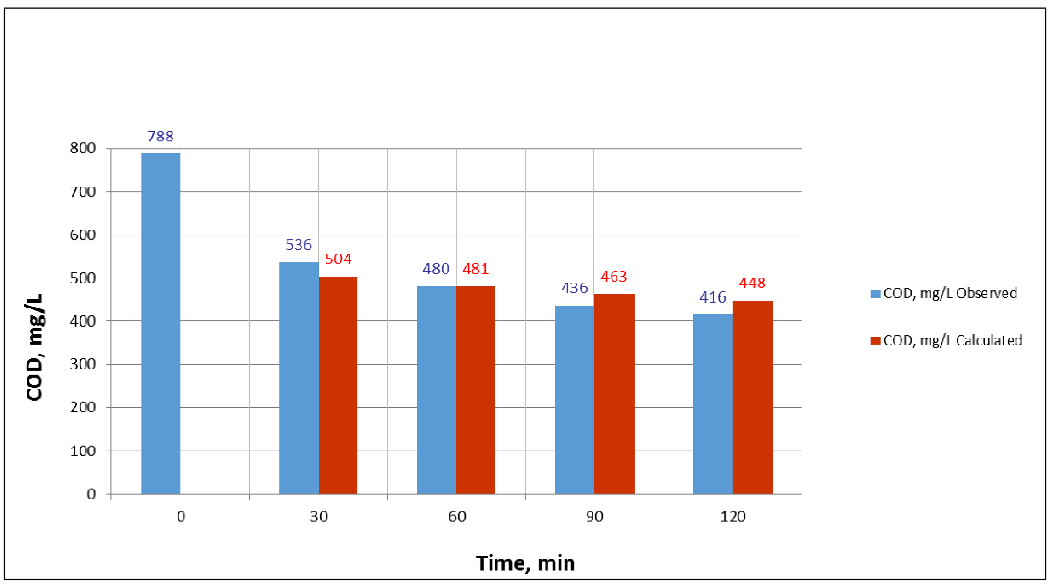


Figure 4.97 COD removal with 40 mL aerobically digested sludge

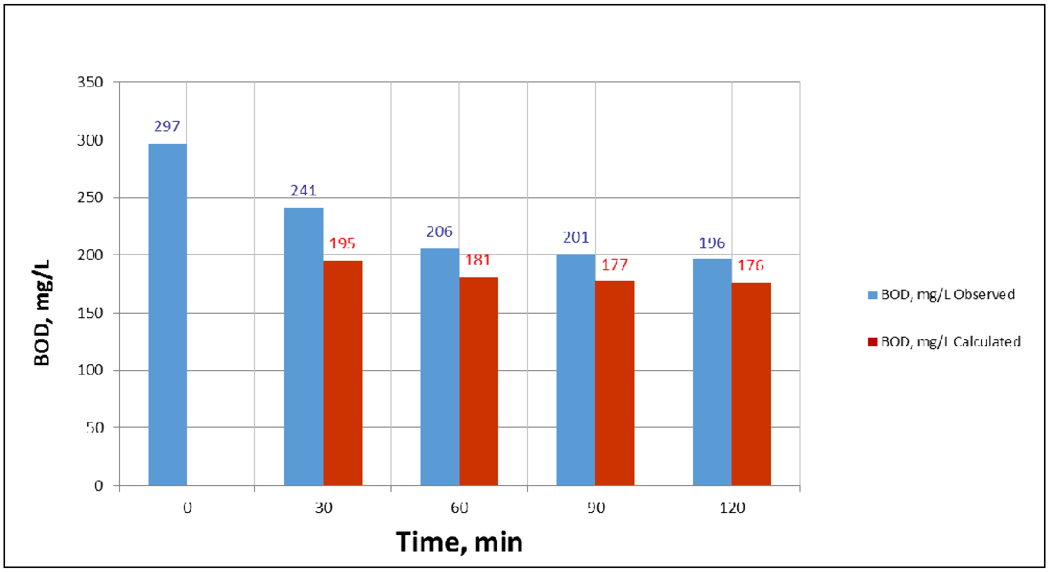


Figure 4.98 BOD removal with 40 mL aerobically digested sludge

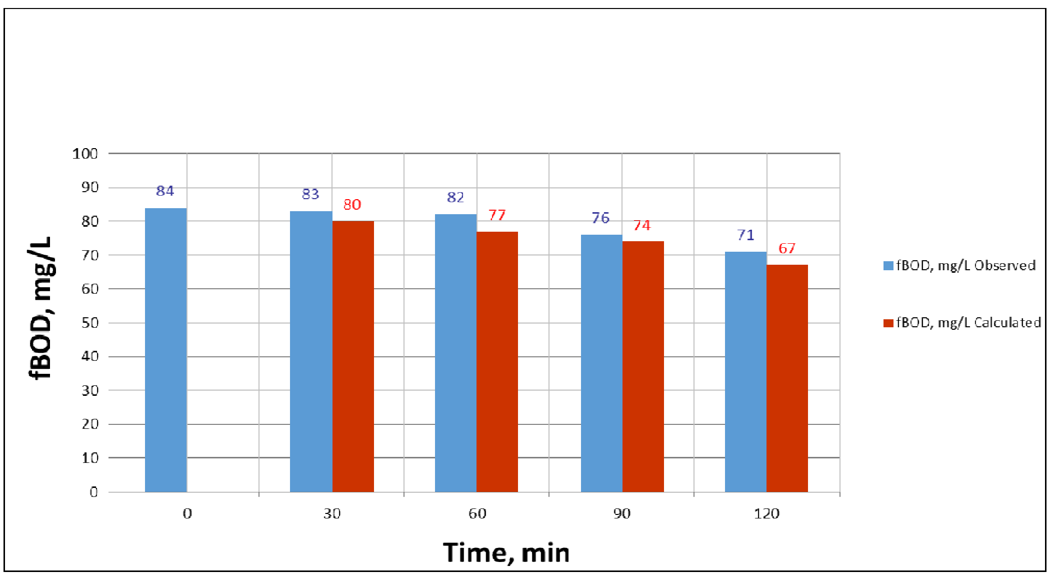


Figure 4.99 fBOD removal with 40 mL aerobically digested sludge

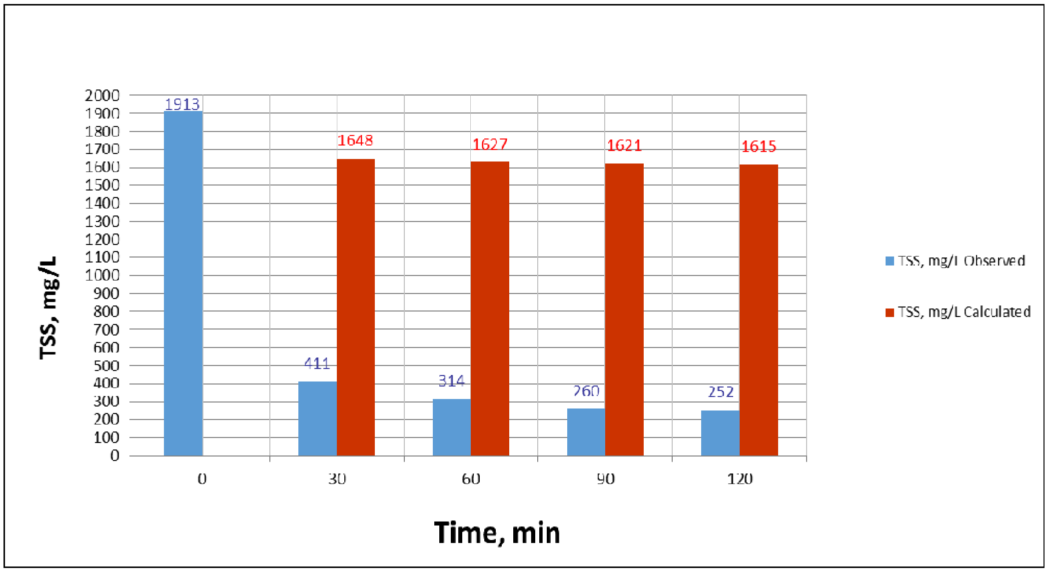


Figure 4.100 TSS removal with 50 mL aerobically digested sludge

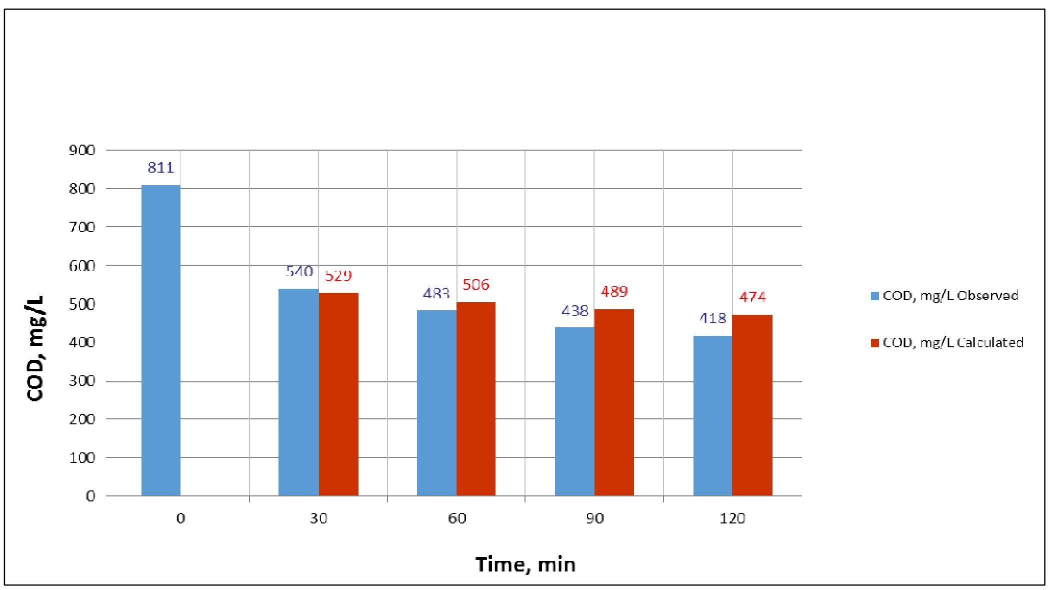


Figure 4.101 COD removal with 50 mL aerobically digested sludge

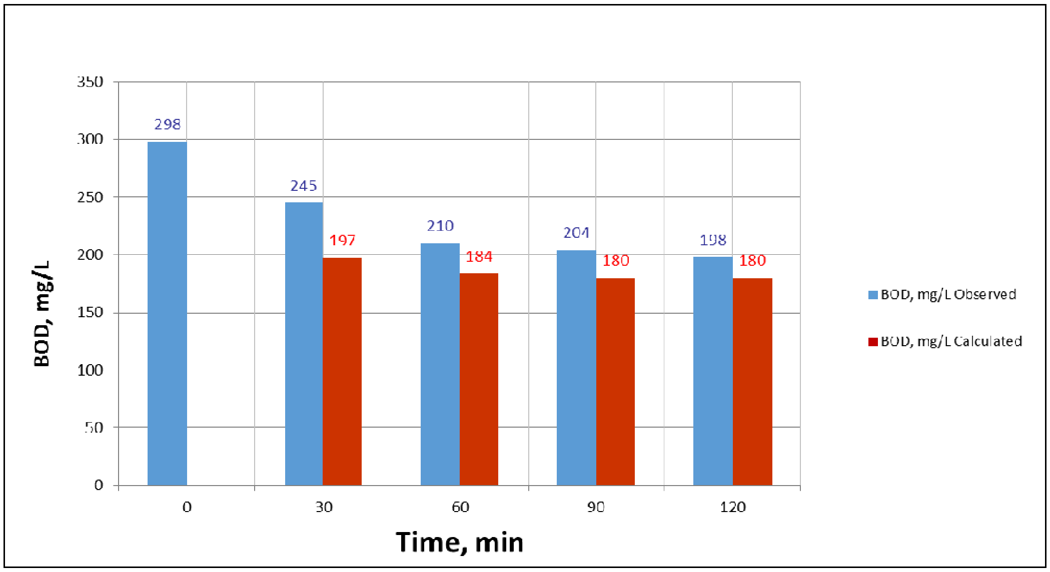


Figure 4.102 BOD removal with 50 mL aerobically digested sludge

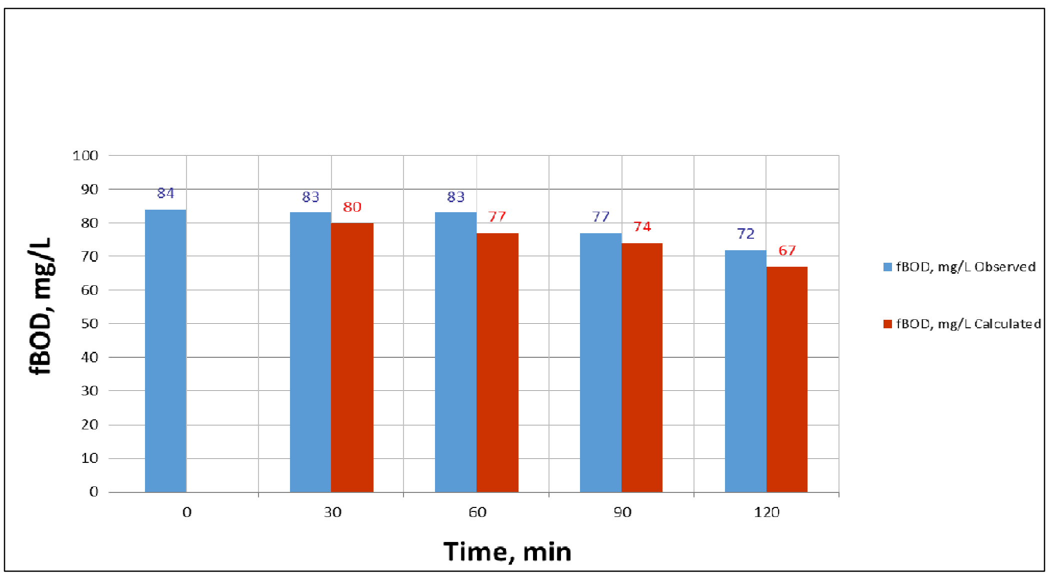


Figure 4.103 fBOD removal with 50 mL aerobically digested sludge

It can be seen from Table 4.84 to 4.103 that the observed removal of TSS, COD, BOD_5 and filtered BOD_5 in first hour was 84 %, 41%, 31 % and 7% respectively establishing that first hour settling is more important in the removal of TSS, COD and BOD_5. In the second hour the additional removal in TSS, COD, BOD_5 and filtered BOD_5 observed were 3%, 13%, 16% and 23 % respectively indicating that the second hour was especially more effective in the removal of filtered BOD (soluble fraction) due to the absorption into the cells, which are high in concentration. The maximum removal in TSS of 87% was observed with the addition of 50 mL sludge after 2 h settling and maximum removal of COD was 54 % with 10 mL sludge after 2 h settling. Maximum removals of 47 and 30 % in BOD & f BOD were observed with addition of 10 mL after 2 h settling. The calculated values of removal in TSS, COD, BOD and fBOD were 39%, 49 %, 43 and 22% with 10 mL of sludge addition. Thus, the observed values were significantly better than the corresponding values of the calculated parameters simulating the existing scenario. The results of this set of observations were best with the addition of 10 mL of this sludge. These were the best results out of all the previous experiments, which yielded a clue that the conditioning of the excess thickened sludge through aeration may prove to be very useful as aerobically digested sludge would normally not be available in STPs. Thus, a brief aeration period was given to the thickened sludge of STP Delawas for carrying out another set of settling experiments.

4.2.6. Settling experiments with briefly aerated thickened return sludge from STP Delawas

Aeration of 200 L of thickened sludge was carried out with diffusers operated through a small pump fitted with 0.50 HP motor for 10 min duration. Settling experiments were conducted with 10, 20, 30, 40, and 50 mL of this sludge added to

1000 mL of raw sewage sample VI from STP Delawas. The settling characteristics of raw sewage and the properties of briefly aerated thickened sludge of STP, Delawas are listed in Tables 4.11 and 4.12.

Table 4.5 Results of settling of raw sewage sample VI

Duration, min	TSS, mg/L	TSS removal, %	COD, mg/L	COD removal, %	BOD_5, mg/L	BOD_5 removal, %	Filtered BOD_5, mg/L	$fBOD_5$ removal, %
0	498	0	694	0	286	0	84	0
30	232	53%	390	44%	178	38%	79	6%
60	214	57%	371	47%	165	42%	74	12%
90	206	59%	357	49%	160	44%	71	15%
120	192	61%	332	52%	158	45%	63	25%

Table 4.6 Properties of briefly aerated thickened sludge of STP, Delawas

Parameters	Briefly aerated thickened return sludge of STPDelawas
TSS, mg/L	27890
COD, mg/L	1703
BOD_5, mg/L	460
Filtered BOD_5, mg/L	122

The results of the settling experiments are shown in Figures 4.104 to 4.123

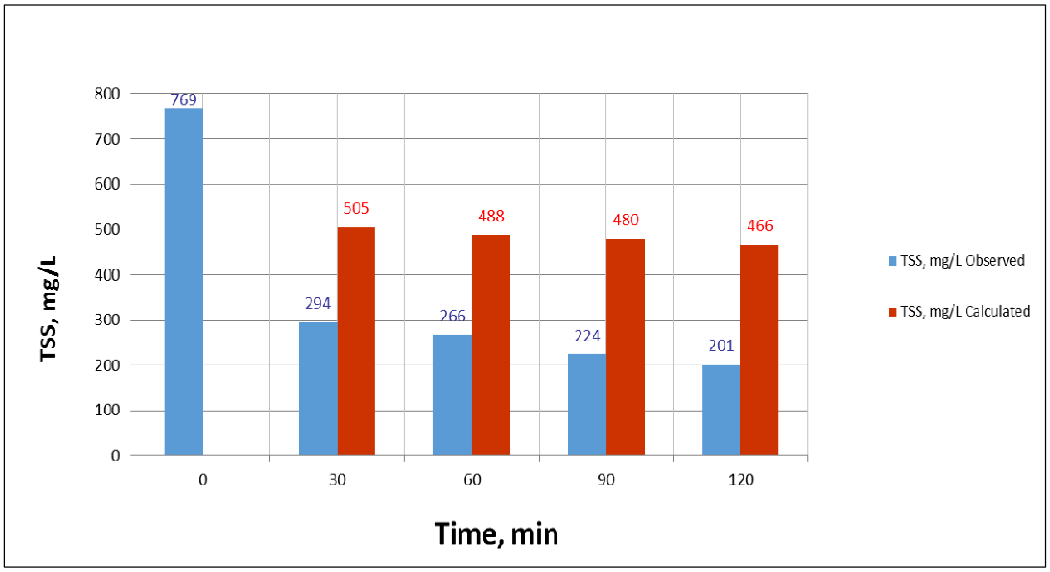


Figure 4.104 TSS removal with 10 mL briefly aerated thickened sludge

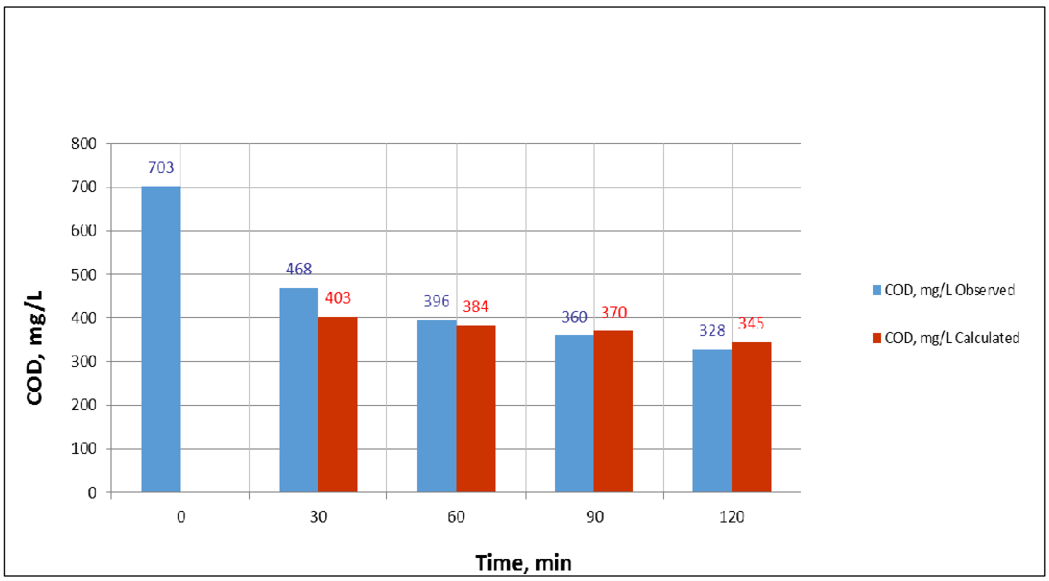


Figure 4.105 COD removal with 10 mL briefly aerated thickened sludge

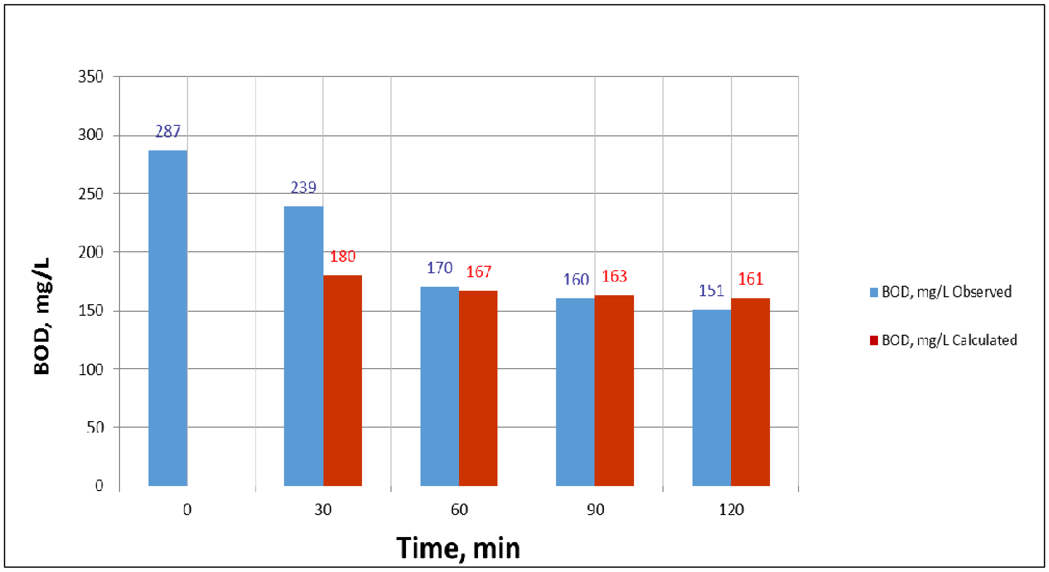


Figure 4.106 BOD removal with 10 mL briefly aerated thickened sludge

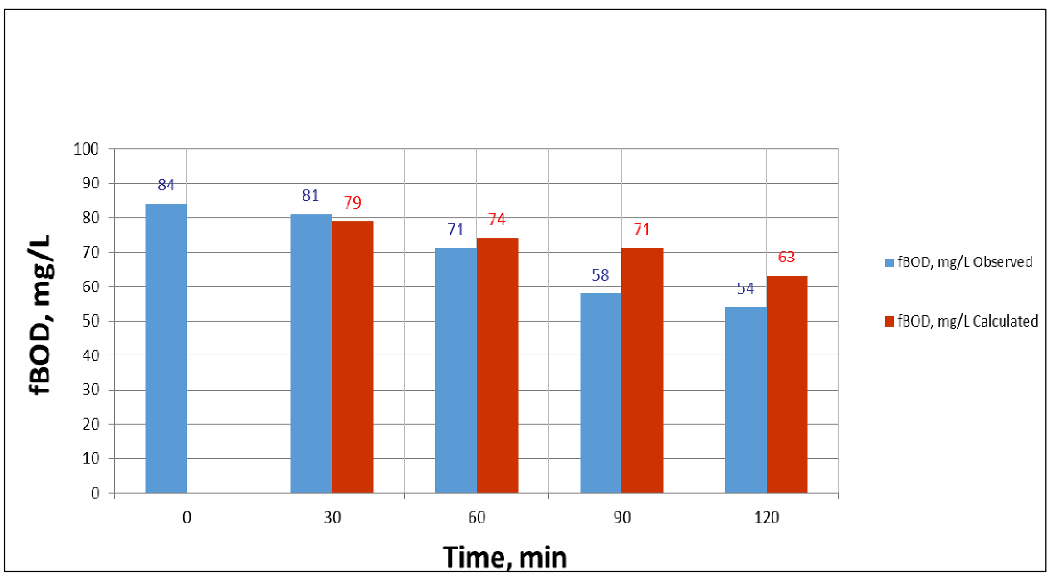


Figure 4.107 fBOD removal with 10 mL briefly aerated thickened sludge

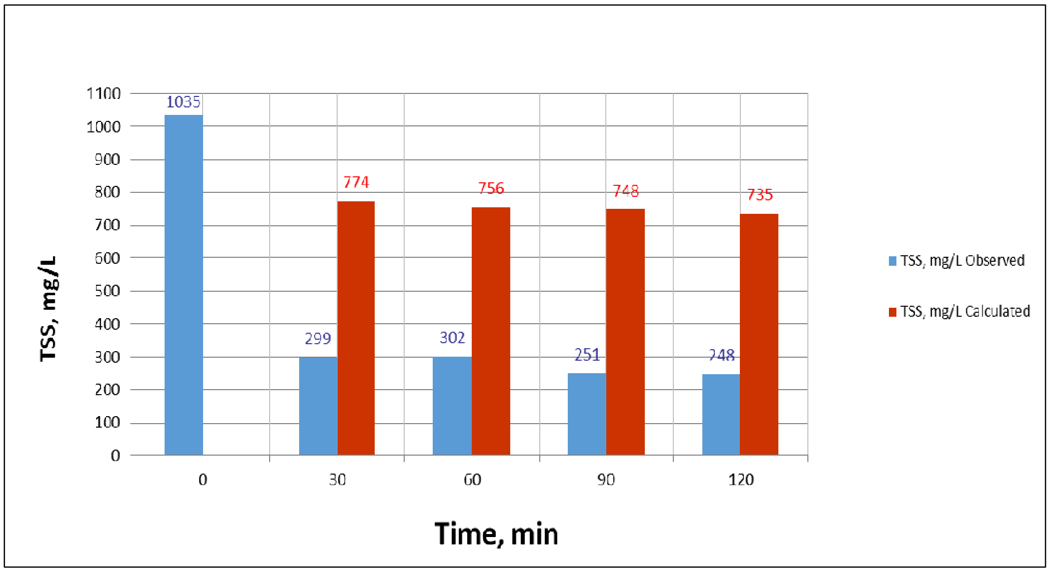


Figure 4.108 TSS removal with 20 mL briefly aerated thickened sludge

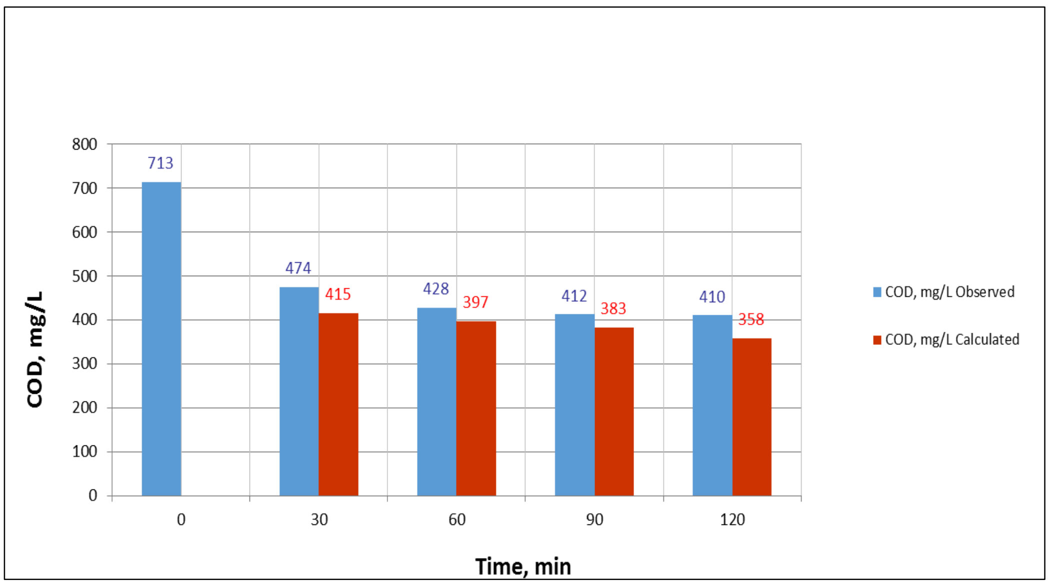


Figure 4.109 COD removal with 20 mL briefly aerated thickened sludge

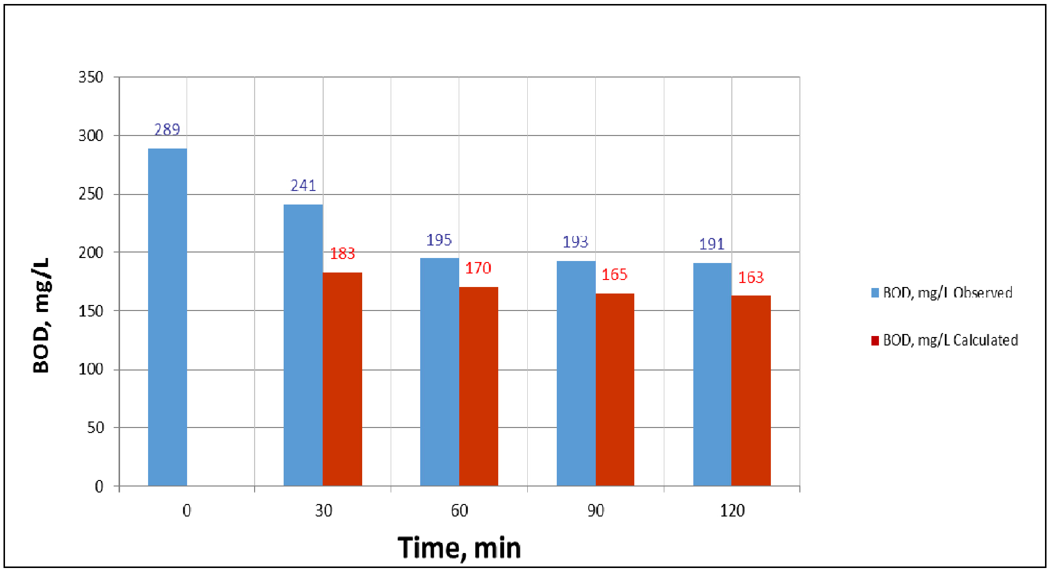


Figure 4.110 BOD removal with 20 mL briefly aerated thickened sludge

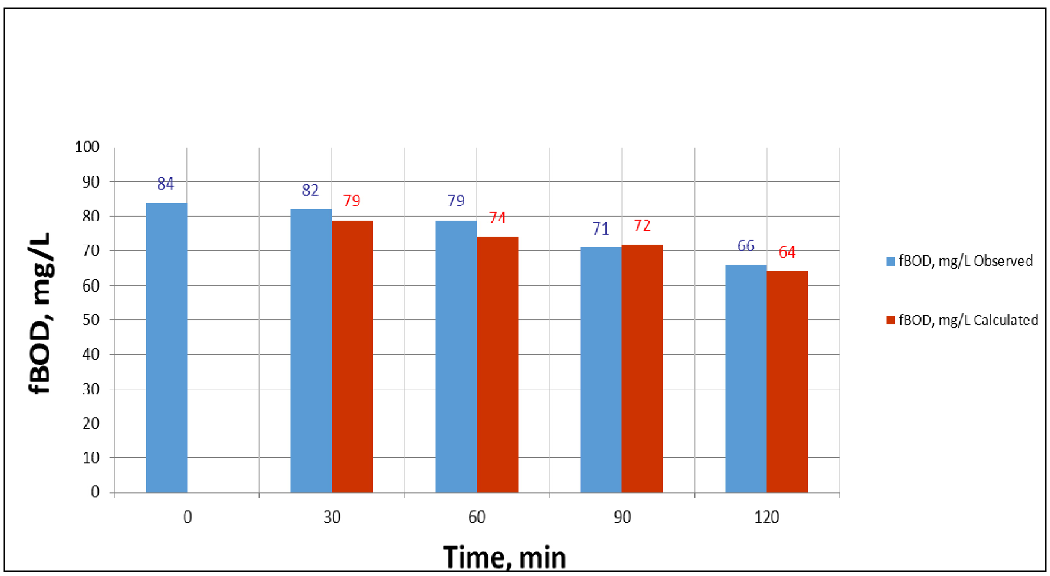


Figure 4.111 fBOD removal with 20 mL briefly aerated thickened sludge

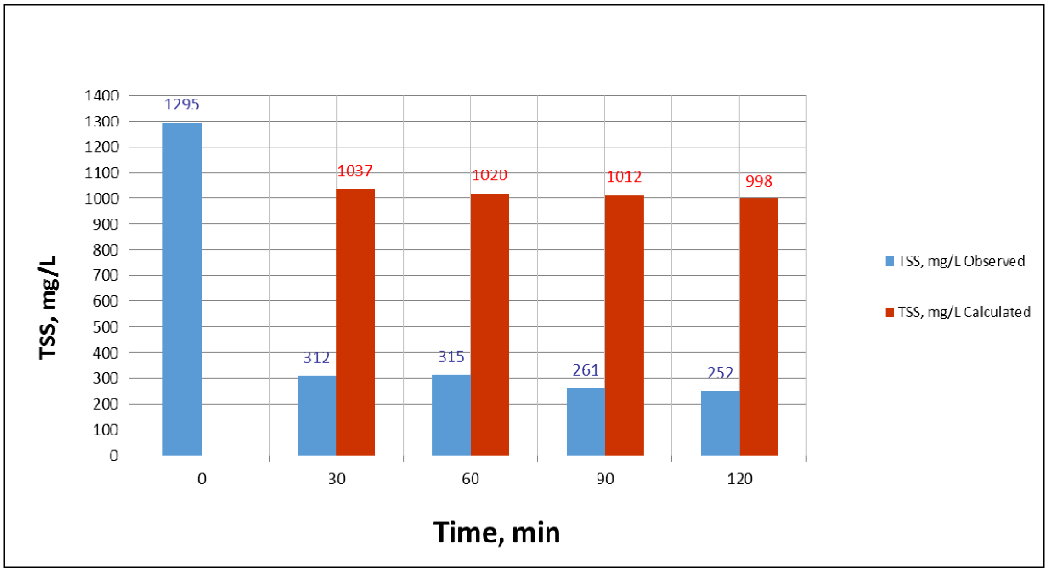


Figure 4.112 TSS removal with 30 mL briefly aerated thickened sludge

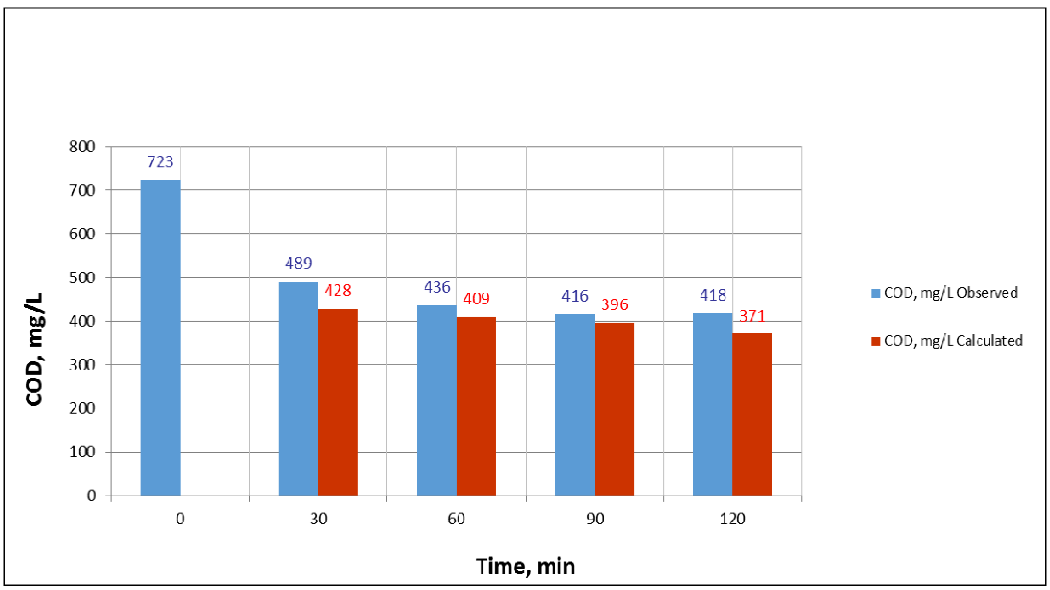


Figure 4.113 COD removal with 30 mL briefly aerated thickened sludge

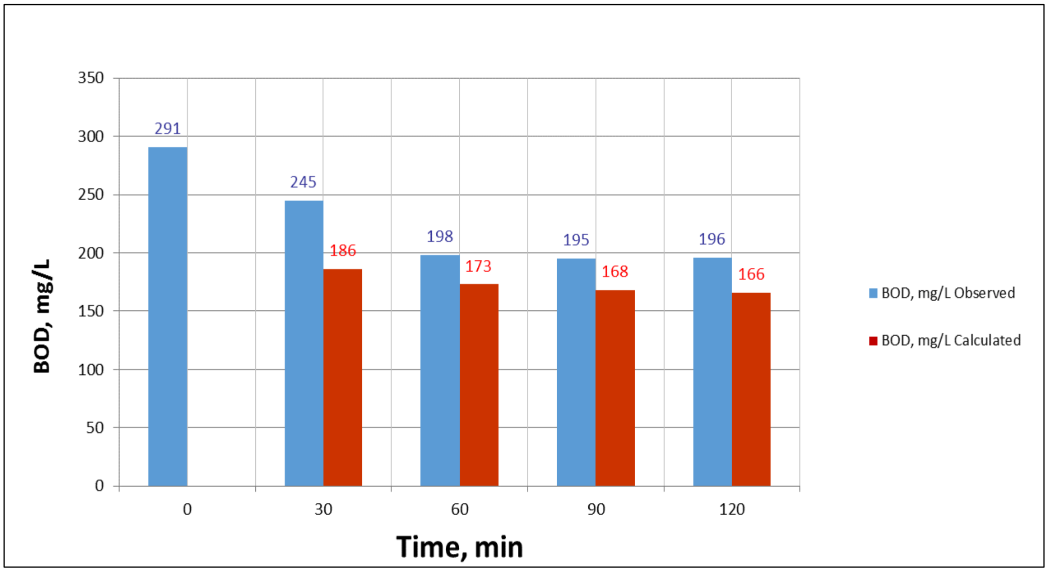


Figure 4.114 BOD removal with 30 mL briefly aerated thickened sludge

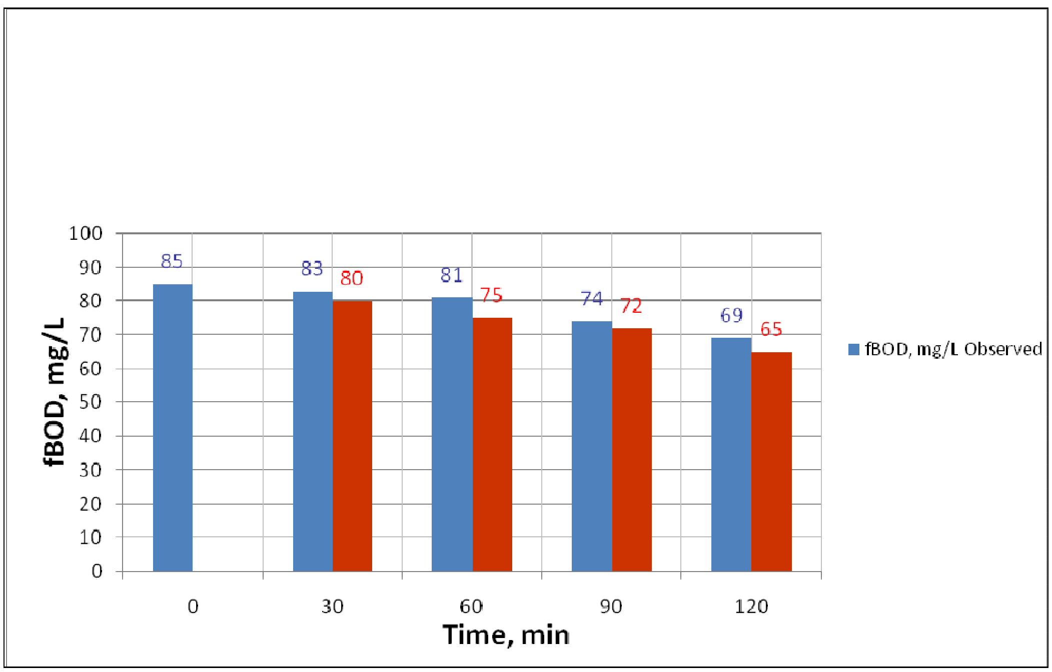


Figure 4.115 fBOD removal with 30 mL briefly aerated thickened sludge

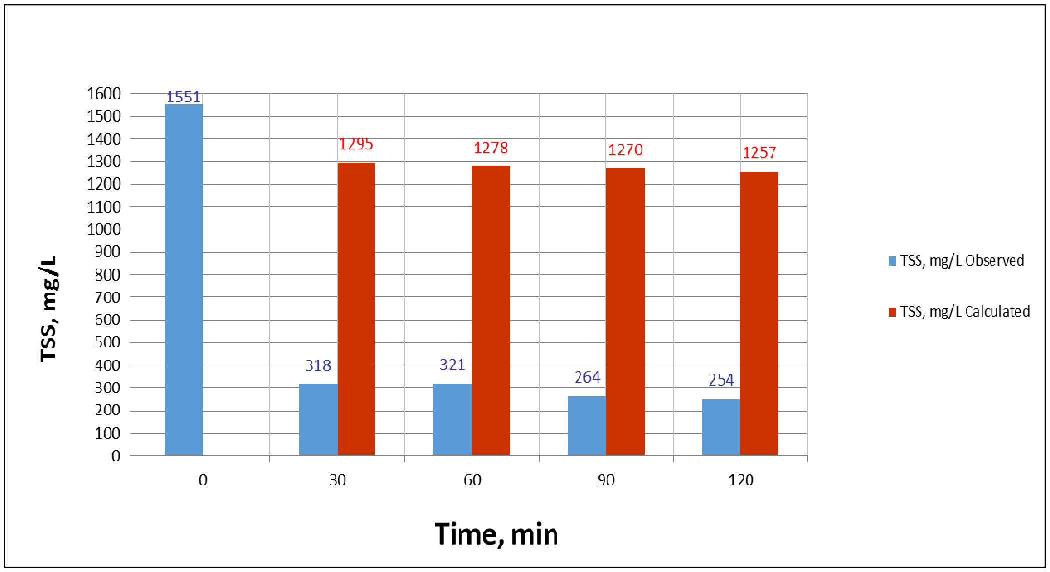


Figure 4.116 TSS removal with 40 mL briefly aerated thickened sludge

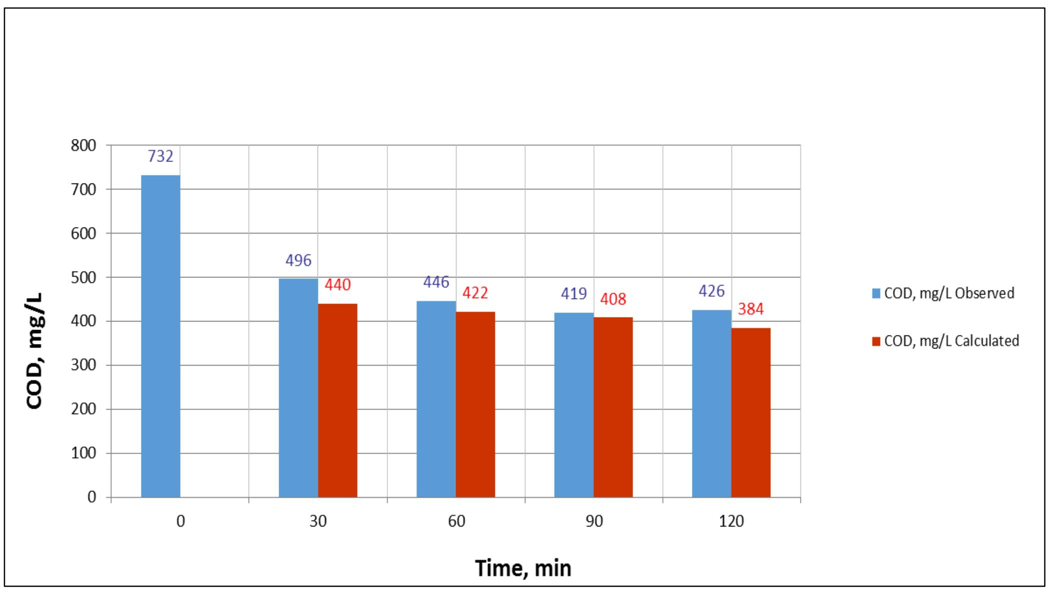


Figure 4.117 COD removal with 40 mL briefly aerated thickened sludge

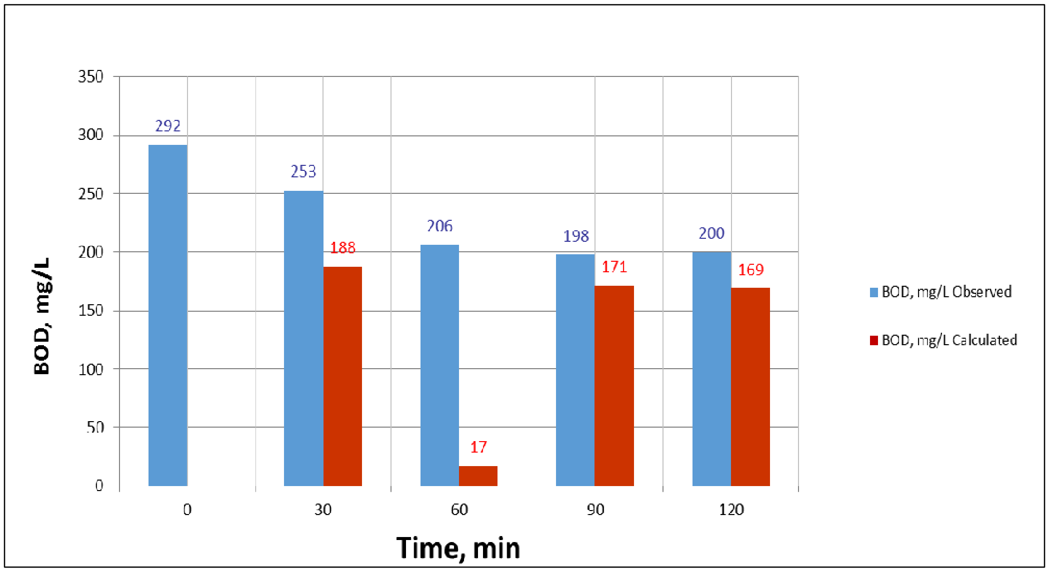


Figure 4.118 BOD removal with 40 mL briefly aerated thickened sludge

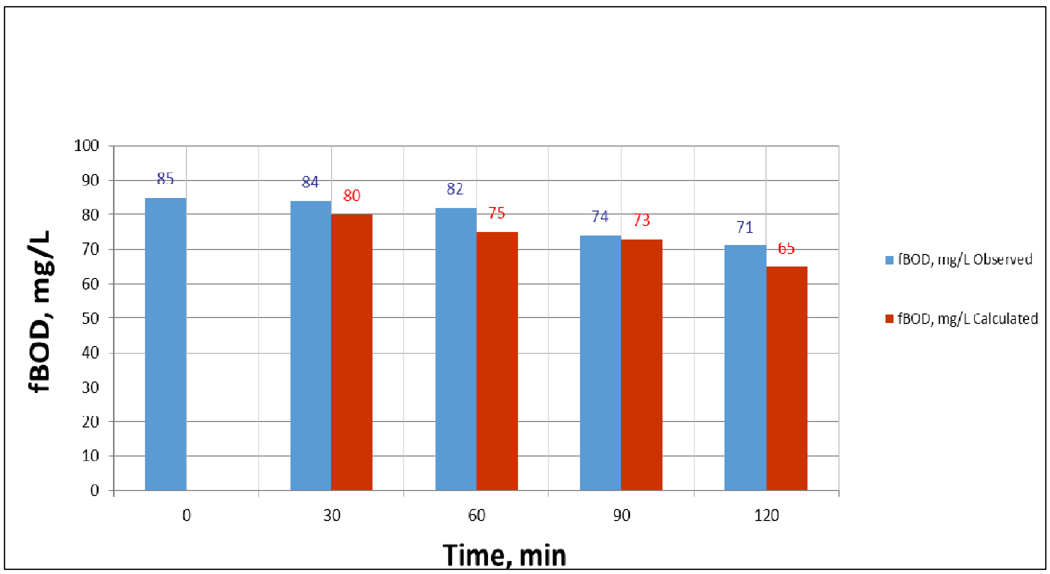


Figure 4.119 fBOD removal with 40 mL brief aerated thickened sludge

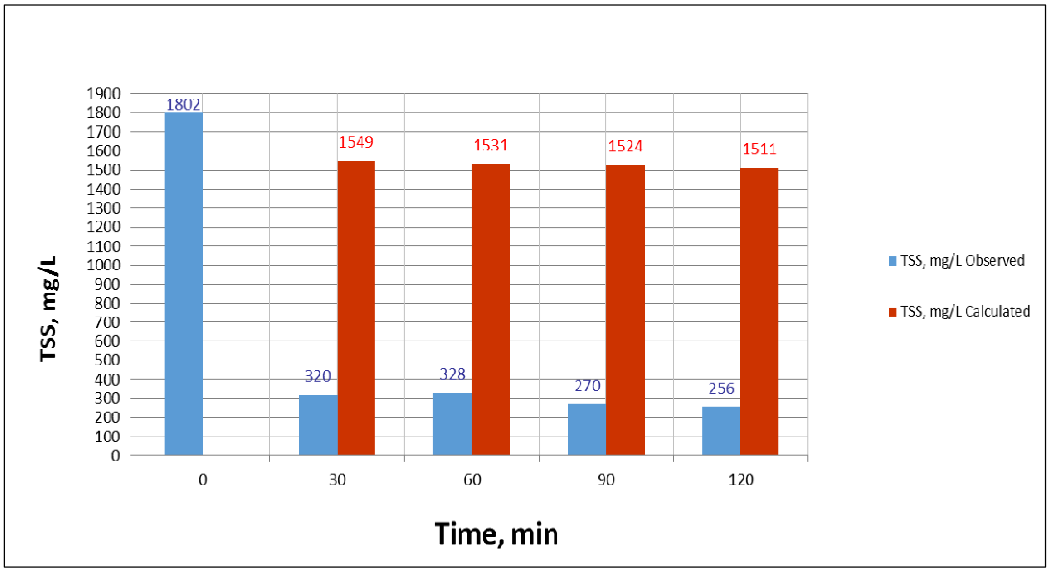


Figure 4.120 TSS removal with 50 mL briefly aerated thickened sludge

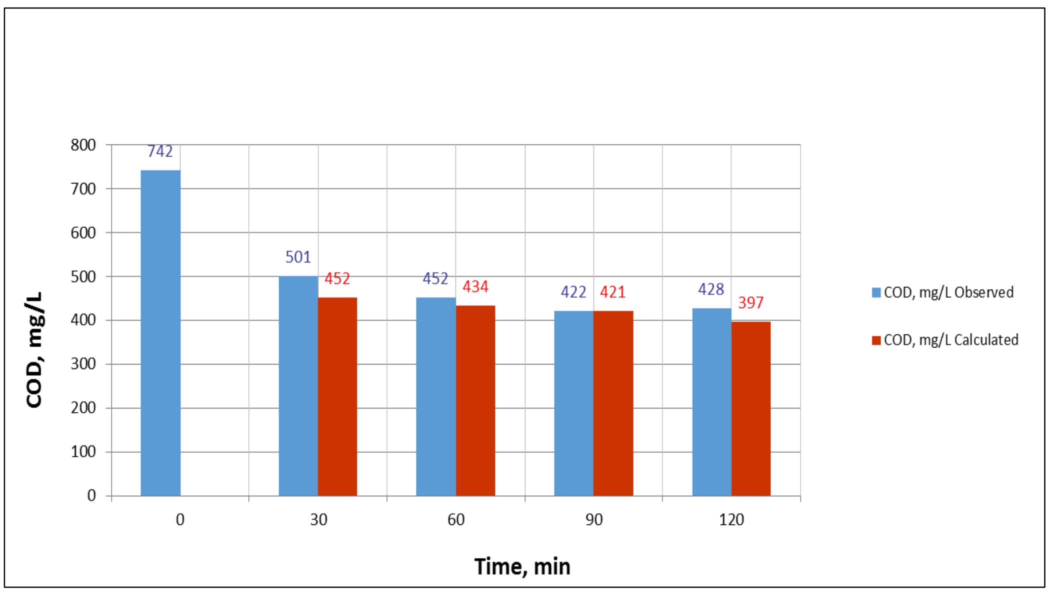


Figure 4.121 COD removal with 50 mL brief aerated thickened sludge

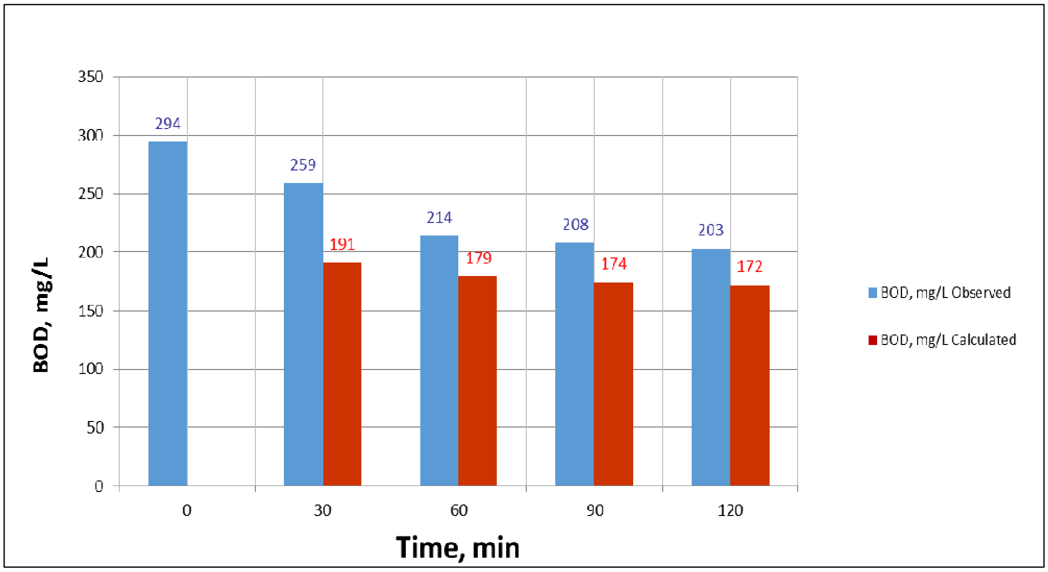


Figure 4.122 BOD removal with 50 mL briefly aerated thickened sludge

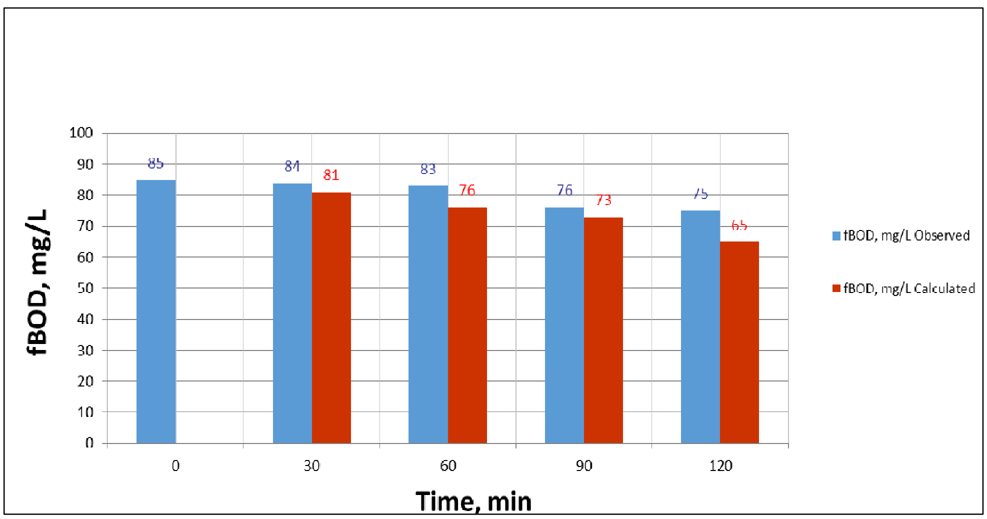


Figure 4.123 fBOD removal with 50 mL briefly aerated thickened sludge

It can be seen from Figure 104 to 4.123 that the observed removal of TSS, COD, BOD_5 and filtered BOD_5 in first hour settling was 80 %, 44%, 41 % and 16% respectively contributing in a major way to the removal of all the parameters. In the second hour, the additional removal in TSS, COD, BOD_5 and filtered BOD_5 observed were 4%, 10%, 7 % and 20 % respectively. It indicated that the second hour also improved the removal of all the parameters further. The maximum removal in TSS of 84% was observed with the addition of 50 mL after 2 h settling, though the removals of other parameters were higher with addition of 10 mL after 2 h settling. The calculated values of removal in TSS, COD, BOD and fBOD were 39%, 51 %, 44 and 25% with 10 mL addition of sludge. Thus, the observed values were much higher than the calculated values representing the existing scenario thereby proving the importance of this step.

In sum, it can be observed from the results that a vast improvement in the process took place after conditioning of the excess sludge from the same plant especially for TSS and BOD_5 removal for 2 h duration of settling at 1% volumetric addition. It was further seen that this process resulted in enhanced efficiency of removal of TSS, COD, BOD and fBOD by 13%, 1%, 3% and 11% respectively over simple settling of raw sewage. Another important observation was the removal of filtered BOD_5 (soluble) by almost 11%, which may be due to absorption of some soluble organics in to the microbial cells as explained above. Results with the addition of 10 mL sludge were the best among the range of 10-50 mL sludge addition. Since the primary sludge has the major contribution in energy generation, we can expect the energy production to enhance due this process modification. Also as lesser amount of suspended organics would enter the aeration system, the energy required for oxidation would also be less resulting in double benefit. No such reports could be traced in literature for the use of conditioned secondary sludge as flocculent in the PST to increase the generation of power with use of primary sludge having more BOD and COD values and hence this modified strategy is a unique contribution to the existing knowledge for STPs having energy generation facility from sludge. Thus, a great promise was indicated in the proposed process modification for saving considerable amount of energy. The higher proportions of sludge addition did not yield very good results probably because of hindered settling. Study results of performance improvement of PST are summarized as below;

1. Results with addition of 30 mL excess sludge for BOD, COD, TSS and fBOD removal at 2 h settling were favorable but a significant gain in terms of filtered BOD removal was obtained due to absorption of soluble substrate in to the microbial cells. The results indicated that sludge as flocculent can be useful.

2. Results with addition of 10 ml thickened sludge indicated the BOD and fBOD removals of 45% and 24% respectively at 2 h settling. These were comparable to results obtained with addition of 30 mL excess sludge without thickening.

3. The addition of 10 ml thickened and briefly aerated sludge resulted in the observed removal of TSS, COD, BOD_5 and filtered BOD_5 of 74 %, 53%, 48 % and 36% respectively showing a vast improvement in the system. These values were 13%, 1%, 3% and 11% higher than those obtained with simple settling of raw sewage for TSS, COD, BOD and fBOD respectively.

4.3. Particle size analysis of suspensions in the PST after flocculation and settling induced by different sludges

Further, to establish the results obtained in earlier experiments, a Jar test was conducted by adding different sludges to sewage and kept with or without agitation for promoting flocculation. In separate experiments, raw sewage was mixed with excess secondary sludge, thickened sludge and also with the same thickened sludge after brief aeration to assess the effect on settling characteristics. The experimental set up is used in the experiment shown in figure 4.124.

Figure 4.124 Experiment set up for Jar test

Initially, 1000 mL of raw sewage was taken in each of the 6 jars, which were added with 10 (control), 20, 30 and 40 mL excess secondary sludge having TSS of 2850 mg/L; and 10 mL thickened sludge having TSS of 28100 mg/L with and without aeration. The system was agitated for 1 min at a high RPM of about 50 and it was left for settling for 2 h. Same exercise was carried out for the similar samples with 1 min of rapid mixing at 100 rpm followed by 10 min of flocculation at 10 rpm and the system was allowed to settle for 110 min to complete a 2 h cycle. Samples were drawn from the top surface of the beakers for the analysis of particles remaining in suspension.

The experiment was carried out at room temperature of about 27^{o}C. All the samples were analyzed for particle size distribution, which was carried out using Mastersizer-2000, Malvern, UK. The graphs for particle size distribution obtained from the analysis are shown at Appendix 1. Volume of particles for 10, 50, 100, and 150 µm size fractions are listed in Table 4.13.

Table 4.7 Volume fraction and particle size distribution of raw sewage with and without addition of sludges in various volumes

S. No.	Sample type	Particle size(µm)				particle size (in µm) where fraction of volume is maximum	Maximum volume fraction	Average particle size (µm)	Volume friction average particle size
		10	50	100	150				
Results after 2 h settling of sample (1 min agitation without flocculation)									
1	Raw sewage								
	Volume (%) of particles	3.80	1.60	3.50	3.70	12	3.95	15.00	4.00
2	Raw sewage + 20 mL excess sludge								
	Volume (%) of particles	4.20	1.90	3.10	2.60	15.00	4.40	15.00	4.40
3	Raw sewage + 30 mL excess sludge								
	Volume (%) of particles	4.50	2.00	2.20	0.50	15.00	5.00	12.00	4.90
4	Raw sewage + 40 mL excess sludge								
	Volume (%) of particles	3.90	2.20	3.40	2.90	15.00	4.20	15.98	4.30
5	Raw sewage + 10 mL excess thickened sludge								
	Volume (%) of particles	3.10	2.60	4.20	3.50	100.00	4.25	24.00	3.00
6	Raw sewage + 10 mL briefly aerated excess sludge								
	Volume (%) of particles	4.50	1.10	1.20	4.00	100.00	0.50	11.57	4.90

S. No.	Sample type	Particle size(µm)				particle size (in µm) where fraction of volume is maximum	Maximum volume fraction	Average particle size (µm)	Volume friction average particle size
		10	50	100	150				
Results after 2 h settling of sample (1 min agitation and 10 min flocculation followed by settling)									
1	Raw sewage								
	Volume (%) of particles	3.70	2.20	5.30	4.00	100	5.30	15.49	2.10
2	Raw sewage + 20 mL excess sludge								
	Volume (%) of particles	2.20	3.00	6.90	6.00	110.00	6.80	56.35	3.50
3	Raw sewage + 30 mL excess sludge								
	Volume (%) of particles	2.40	3.50	6.00	5.50	100.00	6.00	56.33	4.80
4	Raw sewage + 40 mL excess sludge								
	Volume (%) of particles	3.50	1.70	3.80	3.60	110.00	4.00	20.94	2.50
5	Raw sewage + 10 mL excess thickened sludge								
	Volume (%) of particles	2.80	2.20	3.40	3.30	100.00	3.40	23.46	2.80
6	Raw sewage + 10 mL brief aerated excess sludge								
	Volume (%) of particles	3.50	2.10	3.60	3.40	100.00	3.60	21.90	3.10

The results presented in Table 4.13 indicate that the volume fraction of particles after mixing and plain settling increased only marginally after adding return sludge to the sample despite a large amount of solids added to the system. The average particle size decreased from 15 to 12 µm at return sludge addition of 30 mL to 1 L of sewage supporting our earlier results of similar trials. These data verify the fact that the improved solids removal was obtained in the new scheme of returning the sludge to PST with a smaller cut off size for the particles removed by the PST. As the thickened sludge was added, there was a substantial increase in the average outgoing particle size from the PST but the volume fraction decreased significantly. This may be due to the fact that larger floc size being present in the thickened sludge compared to that of the return sludge but inadequacy of settling of some flocs raising the average size of suspensions, however, the overall solids removal was substantially higher than that of controls. With briefly aerated sludge, the average particle size dropped further to 11.5 µm indicating evident promotion of flocculation in the PST resulting in significant improvement in settling.

It was thus felt that the plain settling in PST after instant mixing for one minute may not be able to promote adequate flocculation and hence a 10-min slow mixing was introduced before allowing the solids to settle for 110 min (total period of 2 h). This series of experiments resulted in further reduction in the volume fraction of the particles at the PST outlet compared to the first series and it also showed an increase in the size of the suspensions. The experiments revealed that the flocculation was greatly enhanced by slow mixing cycle and indicated that introducing a clariflocculator instead of PST fed with return sludge can be a good option wherever energy generation from the sludge is practiced.

4.4. Suggestive Theoretical Energy Calculations after modification

The power saving calculation has been carried out as per results obtained in the study. This is a theoretical work with the assumption that there is no change in the existing process, air supply system and DO levels, and only an adjustment in the recirculation ratio of return sludge has been made. The calculations are listed in Table 4.14.

Table 4.8 Power saving calculations for STP operation after performance improvement of PST

Item description	As per existing design	As per field data	After efficiency improvement of PST with addition of 1% aerated thickened return sludge	
Flow, Design	62.50	62.50	62.50	MLD
BOD inlet at inlet chamber	300.00	276.00	286	mg/L
BOD removal in primary treatment	40.00	45.00	48	%
BOD at inlet of Aeration Tank, S_i	180.00	160.00	151	mg/ L
BOD load	468	416	396	kg/h
	11250	10000	9500	kg/day
BOD outlet, S_o	30	30	30	mg/L
BOD removal efficiency, $(S_i-S_o)/S_i*100$	83	81	80	%
BOD removed	9375	8125	7625	kg/day
MLSS	2500	2500	2500	mg/L
MLVSS	2000	2000	2000	mg/L
HRT	6.01	4.1	6.01	h
F/M	0.30	0.26	0.24	
MLSS in the settled sludge	10000	8000	10000	mg/L

Item description	As per existing design	As per field data	After efficiency improvement of PST with addition of 1% aerated thickened return sludge	
Recirculation flow, Qr = Q*[MLSS/(10000-MLSS)]	868	868	868	m^3/h
Provided Qr =50% of inflow, i.e.(needs to configure as suggested in study	1302	1302	651 /1302	m^3/h
O_2 reqd.= [Q*(Si - So)/(1000*f)]-1.42*Px	8227	6389	5700	kg/day
kg O_2/kg BOD removed	0.88	0.79	0.73	
O_2 to be provided	0.88	0.79	0.73	kg/kg of BOD
O_2 to be provided	8227	6389	5653	kg/day
AIR REQUIREMENT				
kg of O_2 required/kg of BOD provided	1.00	1.00	1.00	kg/kg of BOD
Kg of O_2 required	9375.00	8125.00	7625.00	kg/day
	390.63	338.54	317.71	kg/h
Air density @ ambient	1.20	1.20	1.20	kg/m^3
O_2 fraction in air	0.23	0.23	0.23	
Alpha factor	0.70	0.70	0.70	
Beta factor	1.00	1.00	1.00	
Diffuser efficiency @ 3.8 m LD	0.23	0.23	0.23	
Oxygen to be supplied at 37°C	565	489	459	kg/h
(i)Air to be supplied	8905	7718	7243	Nm^3/h
(ii) Oxygen to be supplied	624.86	541.55	508.22	kg/h
Air to be supplied at 14°C	9843	8530	8005	Nm^3/h
Air to be supplied **14°C** at site altitude	10281	8910	8361	m^3/h

Item description	As per existing design	As per field data	After efficiency improvement of PST with addition of 1% aerated thickened return sludge	
Reduction in Air requirement			548	m³//h
%age air reduction			6.0%	
In terms of power (assumed for calculation purposes)			6.0%	
During study as per actual data Power consumption in Aeration			61%	
In terms of kWh			5600	kWh
After PST efficiency improvement , power requirement (theoretically)			55%	
Power required in terms of kWh			5264	kWh
Saving in term of kWh, on Aeration			336	kWh
Power required for brief aeration of sludge (as per lab experiment)				
Volume of sludge to be aerated	1.0% of total flow/day		0.625	MLD
			625	m³/day
			625000	L/day
1/2 HP motor- pump used with diffusers for aeration	10 min- 200 L thickened sludge			
Total per day requirement			260	kWh/day
Expected saving/per day	336 - 260		76	kWh/day
	Say		70	kWh/day
Expected Power saving by configuration of return sludge flow pumps.				
Existing power consumption			470	kWh/day
If pumps are synchronized as per sludge to be circulated , required power will be			300	KWh/day
Power saving			170	KWh/day
Power saving in terms of % by synchronizing return sludge pumps and recycling 1% thickened briefly aerated			=	4%

Item description	As per existing design	As per field data	After efficiency improvement of PST with addition of 1% aerated thickened return sludge	
excess/ return sludge				
Power generation increment (theoretical calculation)				
Due to increased sludge volume at PST				
Existing volume of sludge pumping for digestion		87500	L	
Expected volume of sludge after addition of 1% thickened and brief aerated return sludge as flocculent		93750	L	
Gas produced with existing sludge of PST+ excess sludge		6500	Nm^3/day	
expected increase in gas generation		7661	Nm^3/day	
%age increase in gases in the same existing system)		13%		
Power generation to be increased theoretically		13%		
In terms of kWh		1000	kWh	
The variation in gas production is considered by 10% than average power generation would be		900	kWh	
Thus, average power generation with modified scheme would be	900+170+70=1140 kWh			

The energy calculations indicate that the power employed for conditioning the thickened sludge for its aeration was 260 kWh/day and the power saved due to additional reduction in BOD_5 at PST would be 336 kWh/day yielding a net saving of 70 kWh/day. Further the power saving on pumping due to modification in flow rate of return sludge is 170 kWh/day as calculated in Table 4.14 and increase in power generation due to additional primary sludge removed at PST would be 900 kWh/day. Thus, by enhancement of efficiency of PST in the modified scheme, about 13 % extra power can be generated/saved compared to the existing system and 3% by configuration of return sludge flow pumps.

4.5. Study outcome and contribution

A comprehensive study was carried out to improve the performance of PST through controlled mixing of raw sewage entering it with (i) excess secondary sludge (ii) thickened secondary excess sludge and (iii) aerobically digested sludge containing lot of polysaccharides in different proportions to enhance settling of colloidal particles. In a conventional STP based on ASP, sludge is re-circulated to the aeration tank to enhance the concentration of biomass and its flocculation characteristics. In the present study, it has been demonstrated through a series of experiments that a part of the re-circulated sludge, if made to enter the PST, can significantly enhance the removal of relatively finer suspensions from the raw sewage than what was obtained in the absence of it. This slight modification in the flow scheme of the sludge can be made either through the channel or the pipe bringing raw sewage to the PST for adequate mixing or the PST may be converted to a clariflocculator for enhanced removal of suspended organics through PST, which are major contributors to energy generation in the sludge digesters. This would entail marginal extra cost in terms of civil construction, but high increase in energy yield as evidenced by the results of the present study. Researchers have tried to use chemical coagulants to achieve the same in some plants, but this cannot be done on a sustained basis for long as it can induce metal toxicity in the biological process both in the aeration tank as well as in the digesters.

During the experiment, the addition of return sludge in 10 mL to 50 mL volumes resulted in the maximum TSS removal of 65% with 50 mL volume, which was higher as compared to the removal of 61% obtained with plain settling of raw sewage. The similar removals for COD, BOD fBOD were 44% with 30 mL compared to 52% with raw sewage; 47% with 30 mL compared to 45 %; and 24% compared to 25% with raw sewage respectively for a settling time of 2 h. These results encouraged us to design another series of experiments with other types of sludges. The experiment with anaerobically digested sludge of the same STP did not result in performance improvement.

Experiment with thickened return sludge in 10 mL to 50 mL volumes showed maximum TSS removal of 86% with 50 mL compared to 61% with the plain settling of raw sewage. The corresponding values for COD, BOD and fBOD were 53% with 10 mL compared to 52% with raw sewage, 47% with 10 mL compared to 45 % with raw sludge, and 36% compared to 25% with raw sewage for a settling period of 2 h. Thus, the results were found to be more favorable with thickened sludge and especially for the one obtained from extended aeration plant. Hence, it was perceived that a brief aeration of thickened sludge may yield still better results.

A report is available for the use of activated sludge for improving the performance of PST (Yetis and Tarlan, 2002), which indicated the change in TSS removal as a function of sludge age; however, it does not specify the changes in COD or BOD removals. In an another study, Huang and Li (2000) reported that the removals of TSS and COD increased significantly from 52.0 and 35.0% to 61.6 and 48.1% respectively due to the recirculation of primary sludge after brief aeration back to the PST. The results obtained in our study have shown much higher removals of TSS and COD perhaps due to better flocculation characteristics of secondary sludges over primary sludges as well as the higher effect of conditioning through aeration among secondary sludges over that of primary sludge. Another factor is that if the primary sludge gets retained in PST for a longer duration due to recirculation, it may result in producing foul smells. However, no reports could be traced on the use of aerated secondary sludges for enhancing PST settling process for comparing our results.

Chemicals generally should not be used as a substitute for good plant operating processes as they may interfere with the biological process in the long run (Nancy E. Heim et al., 1979). Since only two studies as mentioned above could be traced on the effect of biological sludges on PST performance, a comparison of our results has been made with the effect of chemicals added as flocculent. An experimental work with use of alum as flocculent by Ismail et al., (2011) showed that when an optimum doze of alum @ 60 mg/L was used as coagulant in a pilot scale El Mansoura governorate wastewater treatment plant, located in North Egypt and operated at an optimum retention time of 2.5 h the efficiencies for TSS, COD and BOD were found to be 83%, 65%, and 55% respectively. These values are comparable to those obtained with briefly aerated thickened excess sludge showing removal efficiencies for TSS, COD and BOD of 74%, 53% and 48% respectively with a retention time of 2 h. Long term effects of chemical addition not only add to the operating cost of the system but they also interfere with the biological processes of sewage as well as sludge treatment. The proposed system of present study is eco friendly and there are almost no cost implications and hence we recommend the use of conditioned sludge through thickening as well as brief aeration to enhance the efficiency of PST.

Addition of the excess secondary sludge to the PST would not have any risk and is available in adequate quantity to sustain the system in the long run. Besides, any extra organics removed in the PST from raw sewage, would further reduce the oxygen requirement in the aeration tank and hence yield double benefit of improved settling and enhanced power generation. The present study quantifies the same through a set of carefully designed experiments.

In order to further strengthen the claims, we conducted another set of experiments on raw settled sewage with and without mixing of excess secondary sludges in a controlled fashion and subsequently carried out a particle size analysis of the settled effluent. The experiments indicated that the cut off diameter of particles reduced from 15 to11.5 μm in different sets of experiments.

The average particle size dropped further to 11.5 μm with addition of brief aerated thickened sludge indicating evident promotion of flocculation in the PST. The results of these experiments can be used with high benefits in energy optimization in STPs wherever energy generation is carried out from waste sludges.

4.6. Suggestions to the Operator from this study

Some specific suggestions to the STP operators derived through this study are as follows:

I. Performance analysis of individual units on regular basis should be done rather than monitoring at the inlet and outlet of STP only.

II. Analysis of available data from the plant should be done on a regular basis. The same should be used with a suitable computer software to bring out process efficiencies of different units and in need, if any, to be used to improve the plant performance

III. Monitoring of energy consumption of different units should also be made in a regular manner and it should be used as an indicator of plant performance. Furthermore, power factor analysis of individual motors must be done on a regular basis from data available from control panel.

IV. The dissolved oxygen level lower than the recommended range of 1.0-3.0 mg/L for conventional ASP may result in some extra savings in power, but it can result in prevalence of anaerobic conditions within the flocs. This may proliferate pathogenic counts in secondary treated sewage and may have far more negative consequences on environment than the benefits of power saving. This may further increase the cost of tertiary treatment (disinfection), if required in future to meet the reuse (if any) norms. Such conditions may be avoided through indications obtained from regular monitoring of pH and SVI and reinforced through the analysis for coliforms and pathogens for improving the plant in time.

For performance enhancement, following modification in STP flow diagram is suggested for energy optimization after study work.

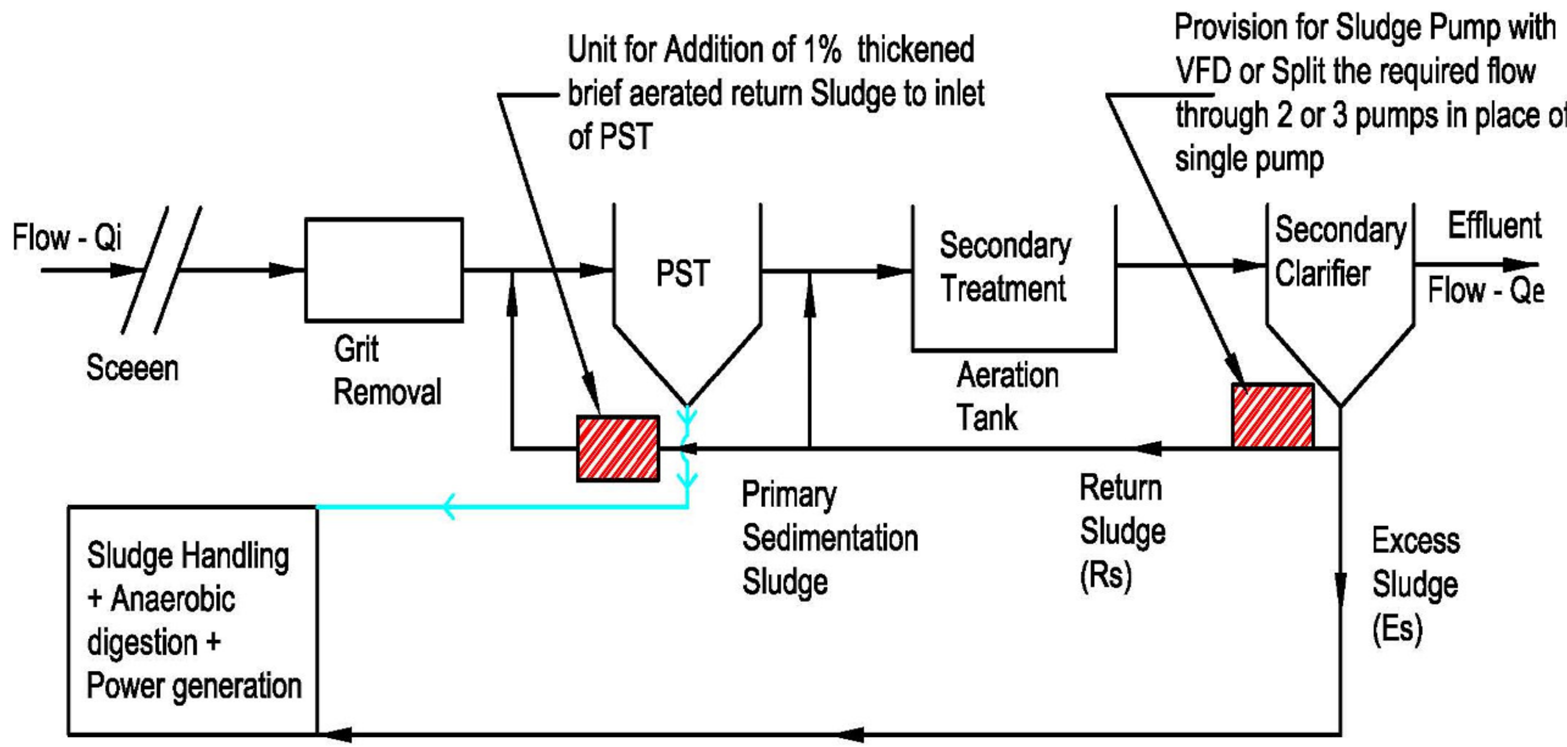


Figure 4.125 Recommended /Modified flow diagram of 62.50 MLD STP unit-I, Delawas Jaipur

CHAPTER 5

CONCLUSION, CONTRIBUTION AND RECOMMENDATION FOR FUTURE WORK

Chapter outlines the conclusions of the research and findings including the contribution of the present research to the existing knowledge. It also discusses the scope for future research in the area.

5.1. Conclusion

A case study for performance analysis of conventional activated sludge process of STP Delawas and use of excess sludge as a flocculent in the primary settling tank was carried out to enhance the operational efficiency of secondary treatment unit and improve the settling characteristics in the primary settling tank.

The STP operating authorities were requested to maintain records of the performance data of the STP, which could be used to derive the efficiencies of individual unit processes/operations. The records of energy usage were also maintained for unit-wise operations. A unique methodology was developed for gaining insight to the performance of an STP through a critical analysis of the routine records of organics removal for deriving kinetic values of the biological process; data on power consumption of individual units at the STP; data on power generation through digester gases; and performance of PST in terms of TSS and BOD removal. Diagnostics were developed through a judicious manipulation of the aforementioned data for the troubleshooting in the plant, which led to the design of a series of experiments for the improvement of PST performance. This approach can help develop protocols for continuous assessment and diagnostics for troubleshooting at

STPs and optimize the process both in terms of organics removal as well as energy demand. The major conclusions derived from this data analysis are as follows:

1. The rate of return sludge flow was excessive, being 50% of the incoming flow of raw sewage resulting in a low HRT of 4 h instead of the design value of 6 h. The data analysis showed that θ_c varied in the range of 6.66 to 12.95 days against its designed value of 8 days. The performance kinetics for oxidation of aeration tank showed that despite low HRT maintained due to excessive rate of return sludge flow, the process did not suffer significantly in terms of organics removal since the SRT was within design limits. However, higher return flow rates affected the cell physiology resulting in impaired performance in terms of settleability and concentration of the secondary sludge biomass.

2. The assessment of energy consumed by different units of the STP showed that the fraction of energy consumed for aeration (60.33%) was lower than the designed value (75%). This was primarily due to low DO level of 0.5 mg/L being maintained in the aeration tank through the application of VFDs. This was also reflected in the fact that the actual consumption of power in the STP was about 20% less than the guaranteed power consumption. Though, it saved some power but a bulk DO of 0.5 mg/L may have resulted in anoxic conditions inside the microbial flocs. As a consequence, the microbiological quality of the treated effluent suffered with a significant increase in coliform and pathogen counts. This also was supported by a marginal decrease in pH in the aeration tank compared to that of raw sewage.

Such a condition can adversely affect the environment and increase the cost of tertiary treatment significantly.

3. The PST performance data showed that there was a BOD_5 removal of about 40% indicating scope for improvement. PSTs have been reported to remove BOD up to 45%. As STP Delawas has a power generation unit that utilizes the digester gases, and primary sludge is the major contributor of energy in the digestion process, it was concluded that any extra removal of organics from PST can yield double benefits of higher energy production in digesters as well as of lesser energy consumption in aeration process as less oxygen demand is reaching the aeration unit. Thus, it was decided to utilize the exo-polymers present in the secondary sludge as flocculent for the PST.

A comprehensive study was designed and carried out to improve the performance of PST through controlled mixing of raw sewage entering it with (i) excess secondary sludge (ii) thickened secondary excess sludge and (iii) aerobically digested sludge containing lot of polysaccharides in different proportions to enhance settling of colloidal particles. In a conventional STP based on ASP, sludge is re-circulated to the aeration tank to enhance the concentration of biomass and its flocculation characteristics. In the present study, it has been demonstrated through a series of experiments that a part of the re-circulated sludge, if made to enter the PST, can significantly enhance the removal of relatively finer suspensions from the raw sewage than what was obtained in the absence of it. This slight modification in the flow scheme of the sludge can be made either through the channel or the pipe bringing raw sewage to the PST for adequate mixing or the PST may be converted to a clariflocculator for enhanced removal of suspended organics through PST, which is a major contributor to energy generation in the sludge digesters. This would entail marginal extra cost in terms of civil construction, but high increase in energy yield as evidenced by the results of the present study.

In our study with addition of 10 mL thickened and briefly aerated excess sludge, the removal efficiencies for TSS, COD, BOD, and fBOD were observed as 74%, 53%, 48% and 36% respectively with retention time of 2 h, which enhanced the efficiency of PST for removal of TSS, BOD, COD & fBOD by 13%, 1%, 3% and 11% over simple settling of raw sewage.

Researchers have tried to use chemical coagulants to achieve the same in some plants, but this could not be done on a sustained basis for long as it can induce metal toxicity in the biological process both in the aeration tank as well as in the digesters. Addition of the excess secondary sludge to the PST would not have any of the above risks and is produced in the process in adequate quantity on sustained basis with system. Hence can be used in long run. Besides, any extra organics removed in the PST from raw sewage, would further reduce the oxygen requirement in the aeration tank and hence yield double benefit of improved settling and enhanced power generation. The present study quantifies the same through a set of carefully designed experiments.

4. In order to further strengthen the claims, another set of experiments on raw settled sewage with and without mixing of excess secondary sludges was conducted in a controlled fashion and subsequently particle size analysis of the settled effluent was carried out. The experiments indicated that the cut off diameter of particles reduced from 15 to 11.5 µm in different sets of experiments.

5. The average particle size dropped further to 11.5 μm with addition of brief aerated thickened sludge indicating evident promotion of flocculation in the PST. The results of these experiments can be used with high benefits in energy optimization in STPs wherever energy generation is carried out from waste sludges.

5.2. Scope for future research

The study can be further extended on the following lines to acquire a better control over the process:

1. A pilot scale study can be carried out in future for evaluation of performance kinetics as well as finding out the benefits of the proposed changes in the flow scheme on a scaled up system. Opportunity to employ the above modification in the flow scheme may be assessed with other aerobic suspended growth processes such as SBR, MBBR especially wherever energy generation provision exists.

2. A detailed particle size analysis can be carried out through column studies using secondary sludges (both raw and conditioned) as flocculent for ascertaining the removal of colloidal suspensions from PST. This can yield information on optimal doze of these sludges as well as help optimize the detention time required in the PST.

3. The controlled conditioning (through aeration) of the secondary sludge to be used as a flocculent should be studied in details.

4. A detailed analysis of the modified scheme involving secondary sludge sent to PST as a flocculent has to be carried out for performance improvement in terms of both soluble and suspended organics. This

can help derive an optimum HRT of PST for its action as a contact tank of the contact-stabilization process.

5. Studies on the application of some poly-electrolytes to enhance organics removal from PST can be made as these are not expected to interfere with the digester operation after being incorporated in the primary sludge.

6. The lower concentration of thickened and conditioned sludge should also be tried for further optimization of the process.

7. Trial run should be carried out under flow conditions in a pilot plant study to develop scale up parameters.

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1. Jangid D.R., Vyas, R.K. Gupta A.B. (2008), Energy Conservation and cost recovery from 62.50 MLD STP Delawas, Jaipur- A case study- Proceedings of National Conference on Hydraulics, Water resources and Environment, HYDRO-2008, December 15-16 ,2008 at MNIT, Jaipur (p. no. 1089-1097)

2. Jangid D.R., Lokwani, J.P. (2008), Cost saving through Energy Audit and NRW study of water supply schemes in Rajasthsn- A case study- Proceedings of National Conference on Hydraulics, Water resources and Environment, HYDRO-2008 , December 15-16, 2008 at MNIT, Jaipur (p. no. 896-910)

3. Jangid D.R., Pancholi Payal, Gupta A.B. (2014) - Presentation on Waste to Energy –Power Generation at 62.50 MLD STP Delawas, Jaipur- Rajasthan- A Case Study, 46th IWWA Annual Convention, Bangalore 17^{th}, 18^{th} & 19^{th} January 2014.

4. Jangid D.R. and Gupta A.B. (2014), Waste to Energy –Sewage Treatment Plant Delawas, Jaipur- Rajasthan-India- A case study -*International Journal of recent trends in science and technology*, volume10 (2), pp 308-312.

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Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

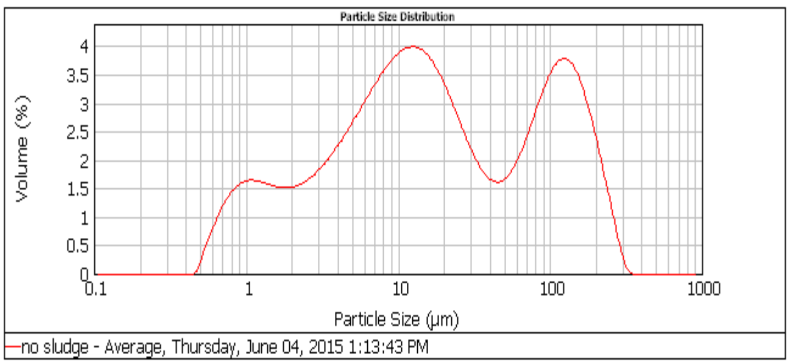
Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: no sludge - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 1:13:43 PM
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 1:13:44 PM
Sample bulk lot ref:	**Result Source:** Averaged	

Particle Name: Default	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.520	**Absorption:** 0.1	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 2.61 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 2.139 %	**Result Emulation:** Off

Concentration: 0.0020 %Vol	**Span :** 9.410	**Uniformity:** 2.69	**Result units:** Volume
Specific Surface Area: 1.18 m²/g	**Surface Weighted Mean D[3,2]:** 5.068 um	**Vol. Weighted Mean D[4,3]:** 47.461 um	

d(0.1): 1.603 um **d(0.5): 15.412 um** **d(0.9): 146.630 um**



Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %
0.010	0.00	0.105	0.00	1.096	1.48	11.482	3.60	120.226	3.40	1258.925	0.00
0.011	0.00	0.120	0.00	1.259	1.43	13.183	3.56	138.038	3.23	1445.440	0.00
0.013	0.00	0.138	0.00	1.445	1.39	15.136	3.42	158.489	2.85	1659.587	0.00
0.015	0.00	0.158	0.00	1.660	1.36	17.378	3.19	181.970	2.31	1905.461	0.00
0.017	0.00	0.182	0.00	1.905	1.38	19.953	2.88	208.930	1.68	2187.762	0.00
0.020	0.00	0.209	0.00	2.188	1.43	22.909	2.52	239.883	1.00	2511.886	0.00
0.023	0.00	0.240	0.00	2.512	1.53	26.303	2.15	275.423	0.36	2884.032	0.00
0.026	0.00	0.275	0.00	2.884	1.67	30.200	1.83	316.228	0.01	3311.311	0.00
0.030	0.00	0.316	0.00	3.311	1.85	34.674	1.59	363.078	0.00	3801.894	0.00
0.035	0.00	0.363	0.00	3.802	2.05	39.811	1.46	416.869	0.00	4365.158	0.00
0.040	0.00	0.417	0.00	4.365	2.28	45.709	1.48	478.630	0.00	5011.872	0.00
0.046	0.00	0.479	0.26	5.012	2.52	52.481	1.64	549.541	0.00	5754.399	0.00
0.052	0.00	0.550	0.66	5.754	2.76	60.256	1.93	630.957	0.00	6606.934	0.00
0.060	0.00	0.631	0.99	6.607	3.01	69.183	2.32	724.436	0.00	7585.776	0.00
0.069	0.00	0.724	1.25	7.586	3.23	79.433	2.74	831.764	0.00	8709.636	0.00
0.079	0.00	0.832	1.41	8.710	3.42	91.201	3.11	954.993	0.00	10000.000	
0.091	0.00	0.955	1.48	10.000	3.55	104.713	3.35	1096.478	0.00		
0.105		1.096		11.482		120.226		1258.925			

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Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: 20rex - Average
SOP Name:
Measured: Thursday, June 04, 2015 1:17:52 PM

Sample Source & type: Supplier
Measured by: bn
Analysed: Thursday, June 04, 2015 1:17:53 PM

Sample bulk lot ref:
Result Source: Averaged

Particle Name: Default
Accessory Name: Hydro 2000MU (A)
Analysis model: General purpose
Sensitivity: Normal

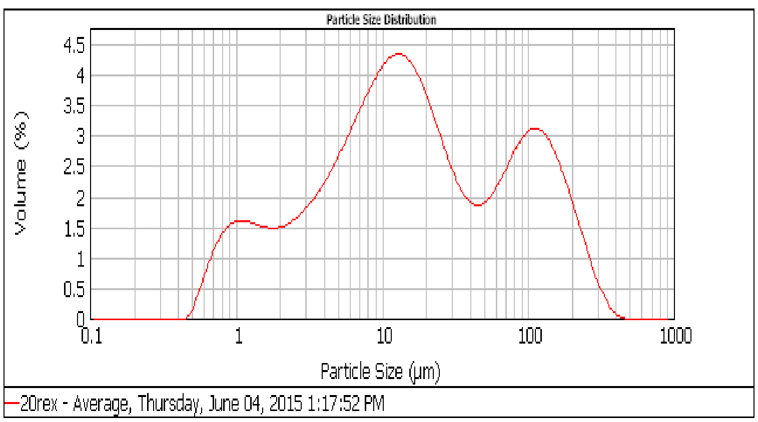
Particle RI: 1.520
Absorption: 0.1
Size range: 0.100 to 1000.000 um
Obscuration: 2.21 %

Dispersant Name: Water
Dispersant RI: 1.330
Weighted Residual: 1.538 %
Result Emulation: Off

Concentration: 0.0017 %Vol
Span : 9.043
Uniformity: 2.57
Result units: Volume

Specific Surface Area: 1.15 m²/g
Surface Weighted Mean D[3,2]: 5.218 um
Vol. Weighted Mean D[4,3]: 44.754 um

d(0.1): 1.687 um **d(0.5): 15.032 um** **d(0.9): 137.618 um**



Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (μm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.00
0.240	0.00
0.275	0.00
0.316	0.00
0.363	0.00
0.417	0.00
0.479	0.17
0.550	0.55
0.631	0.91
0.724	1.19
0.832	1.37
0.955	1.44
1.096	

Size (μm)	Volume In %
1.096	1.44
1.259	1.40
1.445	1.36
1.660	1.34
1.905	1.35
2.188	1.41
2.512	1.51
2.884	1.65
3.311	1.82
3.802	2.03
4.365	2.26
5.012	2.52
5.754	2.80
6.607	3.09
7.586	3.37
8.710	3.61
10.000	3.80
11.482	

Size (μm)	Volume In %
11.482	3.90
13.183	3.89
15.136	3.76
17.378	3.51
19.953	3.17
22.909	2.77
26.303	2.39
30.200	2.05
34.674	1.81
39.811	1.69
45.709	1.69
52.481	1.82
60.256	2.04
69.183	2.31
79.433	2.57
91.201	2.75
104.713	2.82
120.226	

Size (μm)	Volume In %
120.226	2.74
138.038	2.53
158.489	2.22
181.970	1.83
208.930	1.41
239.883	0.98
275.423	0.57
316.228	0.32
363.078	0.08
416.869	0.01
478.630	0.00
549.541	0.00
630.957	0.00
724.436	0.00
831.764	0.00
954.993	0.00
1096.478	0.00
1258.925	

Size (μm)	Volume In %
1258.925	0.00
1445.440	0.00
1659.587	0.00
1905.461	0.00
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

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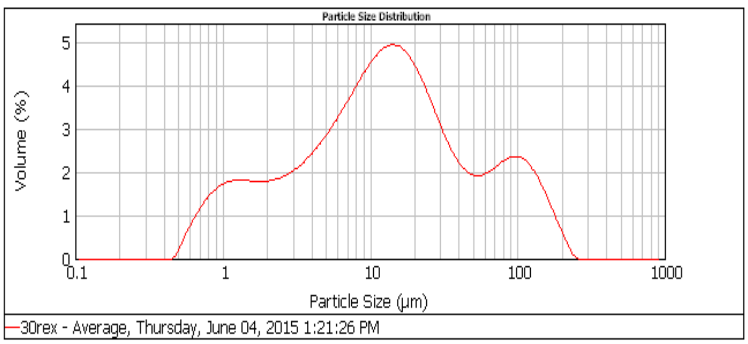
Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: 30rex - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 1:21:26 PM	
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 1:21:27 PM	
Sample bulk lot ref:	**Result Source:** Averaged		
Particle Name: Default	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.520	**Absorption:** 0.1	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 3.18 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.174 %	**Result Emulation:** Off
Concentration: 0.0022 %Vol	**Span :** 6.824	**Uniformity:** 1.84	**Result units:** Volume
Specific Surface Area: 1.28 m²/g	**Surface Weighted Mean D[3,2]:** 4.695 um	**Vol. Weighted Mean D[4,3]:** 28.771 um	

d(0.1): 1.532 um **d(0.5): 12.726 um** **d(0.9): 88.376 um**



Size (µm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (µm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.00
0.240	0.00
0.275	0.00
0.316	0.00
0.363	0.00
0.417	0.00
0.479	0.24
0.550	0.62
0.631	0.95
0.724	1.24
0.832	1.44
0.955	1.57
1.096	

Size (µm)	Volume In %
1.096	1.63
1.259	1.63
1.445	1.62
1.660	1.61
1.905	1.62
2.188	1.66
2.512	1.74
2.884	1.85
3.311	2.01
3.802	2.20
4.365	2.43
5.012	2.69
5.754	2.98
6.607	3.29
7.586	3.62
8.710	3.92
10.000	4.19
11.482	

Size (µm)	Volume In %
11.482	4.38
13.183	4.46
15.136	4.40
17.378	4.21
19.953	3.88
22.909	3.46
26.303	3.00
30.200	2.55
34.674	2.17
39.811	1.89
45.709	1.75
52.481	1.73
60.256	1.81
69.183	1.95
79.433	2.08
91.201	2.13
104.713	2.06
120.226	

Size (µm)	Volume In %
120.226	1.84
138.038	1.50
158.489	1.09
181.970	0.65
208.930	0.24
239.883	0.00
275.423	0.00
316.228	0.00
363.078	0.00
416.869	0.00
478.630	0.00
549.541	0.00
630.957	0.00
724.436	0.00
831.764	0.00
954.993	0.00
1096.478	0.00
1258.925	

Size (µm)	Volume In %
1258.925	0.00
1445.440	0.00
1659.587	0.00
1905.461	0.00
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

Mastersizer 2000 E - [jangid]

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Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

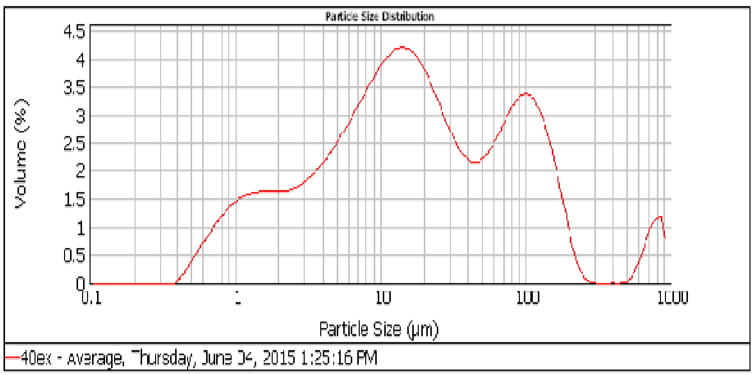
Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: 40ex - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 1:25:16 PM
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 1:25:17 PM
Sample bulk lot ref:	**Result Source:** Averaged	

Particle Name: Default	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.520	**Absorption:** 0.1	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 4.23 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.433 %	**Result Emulation:** Off

Concentration: 0.0034 %Vol	**Span :** 7.767	**Uniformity:** 3.23	**Result units:** Volume
Specific Surface Area: 1.16 m²/g	**Surface Weighted Mean D[3,2]:** 5.174 um	**Vol. Weighted Mean D[4,3]:** 58.033 um	

d(0.1): 1.696 um **d(0.5): 15.982 um** **d(0.9): 125.828 um**



Size (µm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (µm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.00
0.240	0.00
0.275	0.00
0.316	0.00
0.363	0.00
0.417	0.18
0.479	0.37
0.550	0.61
0.631	0.81
0.724	1.01
0.832	1.18
0.955	1.31
1.096	

Size (µm)	Volume In %
1.096	1.40
1.259	1.45
1.445	1.46
1.660	1.46
1.905	1.46
2.188	1.48
2.512	1.54
2.884	1.63
3.311	1.76
3.802	1.93
4.365	2.13
5.012	2.35
5.754	2.60
6.607	2.85
7.586	3.12
8.710	3.36
10.000	3.58
11.482	

Size (µm)	Volume In %
11.482	3.72
13.183	3.78
15.136	3.74
17.378	3.58
19.953	3.22
22.909	2.98
26.303	2.63
30.200	2.30
34.674	2.05
39.811	1.53
45.709	1.55
52.481	2.11
60.256	2.37
69.183	2.66
79.433	2.91
91.201	3.04
104.713	2.98
120.226	

Size (µm)	Volume In %
120.226	2.71
138.038	2.24
158.489	1.64
181.970	0.96
208.930	0.36
239.883	0.06
275.423	0.00
316.228	0.00
363.078	0.00
416.869	0.00
478.630	0.04
549.541	0.27
630.957	0.68
724.436	1.00
831.764	0.93
954.993	0.00
1096.478	0.00
1258.925	

Size (µm)	Volume In %
1258.925	0.00
1445.440	0.00
1659.587	0.00
1905.461	0.00
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

Mastersizer 2000 E - [jangid]

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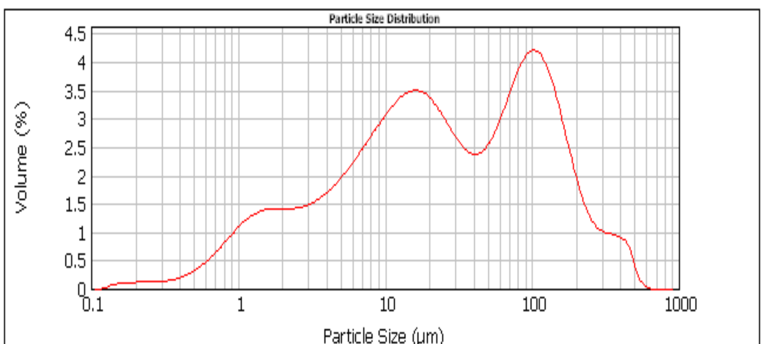
Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990

Sample Name: 10 thickn uf - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 1:29:11 PM	
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 1:29:12 PM	
Sample bulk lot ref:	**Result Source:** Averaged		
Particle Name: Default	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.520	**Absorption:** 0.1	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 6.31 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.393 %	**Result Emulation:** Off
Concentration: 0.0059 %Vol	**Span :** 6.691	**Uniformity:** 2.23	**Result units:** Volume
Specific Surface Area: 1.16 m²/g	**Surface Weighted Mean D[3,2]:** 5.166 um	**Vol. Weighted Mean D[4,3]:** 62.453 um	

d(0.1): 1.958 um **d(0.5): 24.073 um** **d(0.9): 163.043 um**



—10 thickn uf - Average, Thursday, June 04, 2015 1:29:11 PM

Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %
0.010	0.00	0.105	0.00	1.096	1.12	11.482	3.01	120.226	3.50	1258.925	0.00
0.011	0.00	0.120	0.03	1.259	1.21	13.183	3.12	138.038	3.04	1445.440	0.00
0.013	0.00	0.138	0.07	1.445	1.26	15.136	3.15	158.489	2.48	1659.587	0.00
0.015	0.00	0.158	0.10	1.660	1.27	17.378	3.11	181.970	1.89	1905.461	0.00
0.017	0.00	0.182	0.10	1.905	1.27	19.953	2.97	208.930	1.41	2187.762	0.00
0.020	0.00	0.209	0.10	2.188	1.27	22.909	2.77	239.883	1.08	2511.886	0.00
0.023	0.00	0.240	0.11	2.512	1.30	26.303	2.54	275.423	0.92	2884.032	0.00
0.026	0.00	0.275	0.11	2.884	1.35	30.200	2.32	316.228	0.88	3311.311	0.00
0.030	0.00	0.316	0.13	3.311	1.43	34.674	2.17	363.078	0.83	3801.894	0.00
0.035	0.00	0.363	0.16	3.802	1.54	39.811	2.14	416.869	0.73	4365.158	0.00
0.040	0.00	0.417	0.22	4.365	1.68	45.709	2.25	478.630	0.28	5011.872	0.00
0.046	0.00	0.479	0.29	5.012	1.85	52.481	2.50	549.541	0.05	5754.399	0.00
0.052	0.00	0.550	0.40	5.754	2.03	60.256	2.86	630.957	0.00	6606.934	0.00
0.060	0.00	0.631	0.53	6.607	2.23	69.183	3.25	724.436	0.00	7585.776	0.00
0.069	0.00	0.724	0.69	7.586	2.44	79.433	3.59	831.764	0.00	8709.636	0.00
0.079	0.00	0.832	0.84	8.710	2.65	91.201	3.78	954.993	0.00	10000.000	
0.091	0.00	0.955	0.99	10.000	2.84	104.713	3.75	1096.478	0.00		
0.105		1.096		11.482		120.226		1258.925			

Mastersizer 2000 E - [jangid]

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Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

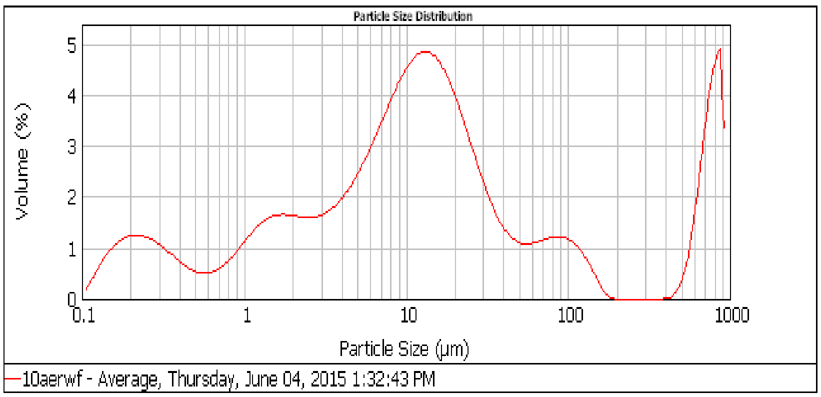
Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name:	SOP Name:	Measured:
10aerwf - Average		Thursday, June 04, 2015 1:32:43 PM
Sample Source & type:	**Measured by:**	**Analysed:**
Supplier	bn	Thursday, June 04, 2015 1:32:44 PM
Sample bulk lot ref:	**Result Source:**	
	Averaged	

Particle Name:	Accessory Name:	Analysis model:	Sensitivity:
Default	Hydro 2000MU (A)	General purpose	Normal
Particle RI:	**Absorption:**	**Size range:**	**Obscuration:**
1.520	0.1	0.100 to 1000.000 um	7.76 %
Dispersant Name:	**Dispersant RI:**	**Weighted Residual:**	**Result Emulation:**
Water	1.330	1.902 %	Off

Concentration:	Span :	Uniformity:	Result units:
0.0051 %Vol	56.357	8.98	Volume
Specific Surface Area:	**Surface Weighted Mean D[3,2]:**	**Vol. Weighted Mean D[4,3]:**	
3.57 m²/g	1.680 um	108.228 um	

d(0.1): 0.625 um **d(0.5): 11.577 um** **d(0.9): 653.066 um**



Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (μm)	Volume In %
0.105	0.29
0.120	0.58
0.138	0.85
0.158	1.01
0.182	1.11
0.209	1.13
0.240	1.08
0.275	0.98
0.316	0.84
0.363	0.69
0.417	0.56
0.479	0.47
0.550	0.45
0.631	0.50
0.724	0.63
0.832	0.82
0.955	1.03
1.096	

Size (μm)	Volume In %
1.096	1.24
1.259	1.39
1.445	1.47
1.660	1.49
1.905	1.47
2.188	1.44
2.512	1.45
2.884	1.50
3.311	1.61
3.802	1.79
4.365	2.04
5.012	2.36
5.754	2.73
6.607	3.13
7.586	3.54
8.710	3.90
10.000	4.19
11.482	

Size (μm)	Volume In %
11.482	4.35
13.183	4.35
15.136	4.18
17.378	3.85
19.953	3.39
22.909	2.85
26.303	2.31
30.200	1.81
34.674	1.42
39.811	1.15
45.709	1.01
52.481	0.97
60.256	1.01
69.183	1.07
79.433	1.10
91.201	1.07
104.713	0.94
120.226	

Size (μm)	Volume In %
120.226	0.73
138.038	0.41
158.489	0.10
181.970	0.00
208.930	0.00
239.883	0.00
275.423	0.00
316.228	0.00
363.078	0.00
416.869	0.05
478.630	0.38
549.541	1.25
630.957	2.65
724.436	3.96
831.764	3.91
954.993	0.00
1096.478	0.00
1258.925	

Size (μm)	Volume In %
1258.925	0.00
1445.440	0.00
1659.587	0.00
1905.461	0.00
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

Mastersizer 2000 E - [jangid]

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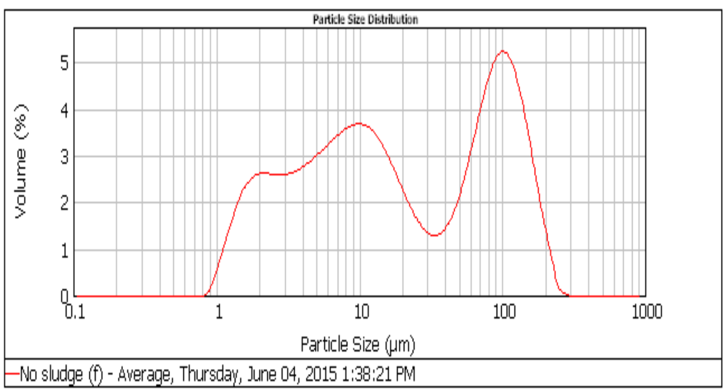
Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: No sludge (f) - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 1:38:21 PM	
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 1:38:22 PM	
Sample bulk lot ref:	**Result Source:** Averaged		
Particle Name: sludge	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.050	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 2.17 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 0.967 %	**Result Emulation:** Off
Concentration: 0.0020 %Vol	**Span :** 8.145	**Uniformity:** 2.57	**Result units:** Volume
Specific Surface Area: 0.9 m²/g	**Surface Weighted Mean D[3,2]:** 6.668 um	**Vol. Weighted Mean D[4,3]:** 45.922 um	

d(0.1): 2.178 um **d(0.5): 15.499 um** **d(0.9): 128.419 um**



Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %
0.010	0.00	0.105	0.00	1.096	1.10	11.482	3.20	120.226	4.13	1258.925	0.00
0.011	0.00	0.120	0.00	1.259	1.65	13.183	2.97	138.038	3.33	1445.440	0.00
0.013	0.00	0.138	0.00	1.445	2.05	15.136	2.66	158.489	2.38	1659.587	0.00
0.015	0.00	0.158	0.00	1.660	2.28	17.378	2.28	181.970	1.45	1905.461	0.00
0.017	0.00	0.182	0.00	1.905	2.36	19.953	1.89	208.930	0.67	2187.762	0.00
0.020	0.00	0.209	0.00	2.188	2.36	22.909	1.54	239.883	0.08	2511.886	0.00
0.023	0.00	0.240	0.00	2.512	2.34	26.303	1.29	275.423	0.00	2884.032	0.00
0.026	0.00	0.275	0.00	2.884	2.35	30.200	1.16	316.228	0.00	3311.311	0.00
0.030	0.00	0.316	0.00	3.311	2.40	34.674	1.20	363.078	0.00	3801.894	0.00
0.035	0.00	0.363	0.00	3.802	2.50	39.811	1.42	416.869	0.00	4365.158	0.00
0.040	0.00	0.417	0.00	4.365	2.63	45.709	1.83	478.630	0.00	5011.872	0.00
0.046	0.00	0.479	0.00	5.012	2.78	52.481	2.42	549.541	0.00	5754.399	0.00
0.052	0.00	0.550	0.00	5.754	2.94	60.256	3.13	630.957	0.00	6606.934	0.00
0.060	0.00	0.631	0.00	6.607	3.10	69.183	3.85	724.436	0.00	7585.776	0.00
0.069	0.00	0.724	0.00	7.586	3.24	79.433	4.43	831.764	0.00	8709.636	0.00
0.079	0.00	0.832	0.08	8.710	3.32	91.201	4.71	954.993	0.00	10000.000	
0.091	0.00	0.955	0.55	10.000	3.31	104.713	4.62	1096.478	0.00		
0.105		1.096		11.482		120.226		1258.925			

Mastersizer 2000 E - [jangid]

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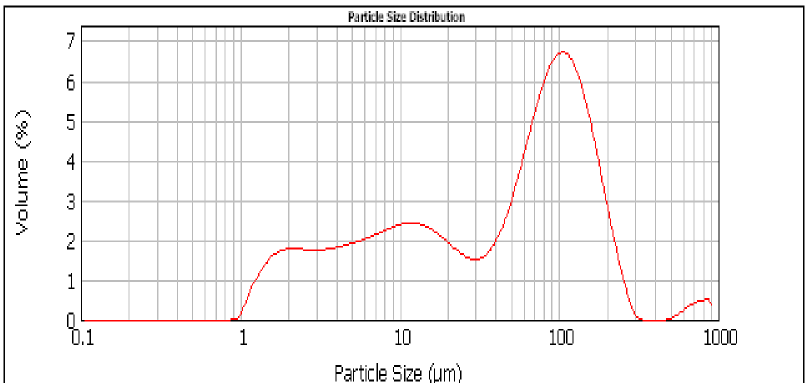
Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: 20rasf - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 1:45:00 PM	
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 1:45:01 PM	
Sample bulk lot ref:	**Result Source:** Averaged		
Particle Name: sludge	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.050	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 3.76 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 0.620 %	**Result Emulation:** Off
Concentration: 0.0053 %Vol	**Span :** 2.846	**Uniformity:** 1.08	**Result units:** Volume
Specific Surface Area: 0.612 m^2/g	**Surface Weighted Mean D[3,2]:** 9.807 um	**Vol. Weighted Mean D[4,3]:** 76.435 um	

d(0.1): 2.941 um **d(0.5): 56.351 um** **d(0.9): 163.309 um**



20rasf - Average, Thursday, June 04, 2015 1:45:00 PM

Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (μm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.00
0.240	0.00
0.275	0.00
0.316	0.00
0.363	0.00
0.417	0.00
0.479	0.00
0.550	0.00
0.631	0.00
0.724	0.00
0.832	0.01
0.955	0.17
1.096	

Size (μm)	Volume In %
1.096	0.74
1.259	1.10
1.445	1.41
1.660	1.56
1.905	1.61
2.188	1.60
2.512	1.58
2.884	1.58
3.311	1.60
3.802	1.65
4.365	1.70
5.012	1.76
5.754	1.84
6.607	1.93
7.586	2.03
8.710	2.12
10.000	2.18
11.482	

Size (μm)	Volume In %
11.482	2.19
13.183	2.14
15.136	2.02
17.378	1.86
19.953	1.66
22.909	1.49
26.303	1.38
30.200	1.39
34.674	1.58
39.811	1.97
45.709	2.56
52.481	3.32
60.256	4.16
69.183	4.97
79.433	5.63
91.201	6.00
104.713	6.02
120.226	

Size (μm)	Volume In %
120.226	5.65
138.038	4.91
158.489	3.94
181.970	2.83
208.930	1.76
239.883	0.85
275.423	0.16
316.228	0.00
363.078	0.00
416.869	0.00
478.630	0.04
549.541	0.19
630.957	0.34
724.436	0.43
831.764	0.41
954.993	0.00
1096.478	0.00
1258.925	

Size (μm)	Volume In %
1258.925	0.00
1445.440	0.00
1659.587	0.00
1905.461	0.00
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

Mastersizer 2000 E - [jangid]

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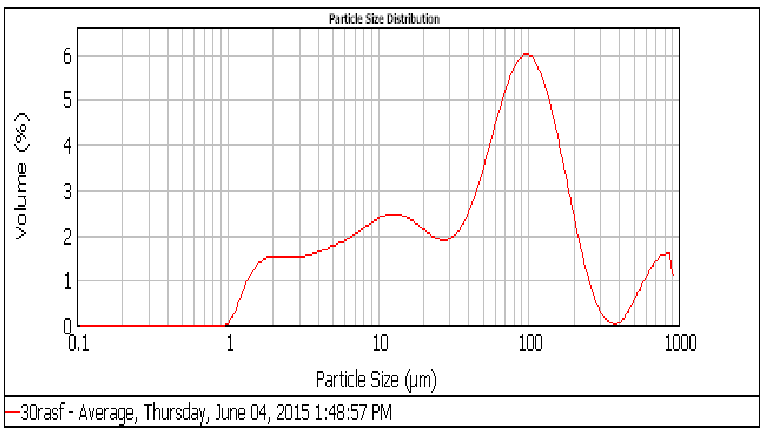
Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: 30rasf - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 1:48:57 PM	
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 1:48:58 PM	
Sample bulk lot ref:	**Result Source:** Averaged		
Particle Name: sludge	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.050	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 5.08 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 0.605 %	**Result Emulation:** Off
Concentration: 0.0085 %Vol	**Span :** 3.289	**Uniformity:** 1.47	**Result units:** Volume
Specific Surface Area: 0.53 m²/g	**Surface Weighted Mean D[3,2]:** 11.318 um	**Vol. Weighted Mean D[4,3]:** 100.561 um	

d(0.1): 3.553 um **d(0.5): 56.334 um** **d(0.9): 188.814 um**



Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (μm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.00
0.240	0.00
0.275	0.00
0.316	0.00
0.363	0.00
0.417	0.00
0.479	0.00
0.550	0.00
0.631	0.00
0.724	0.00
0.832	0.00
0.955	0.05
1.096	

Size (μm)	Volume In %
1.096	0.42
1.259	0.86
1.445	1.17
1.660	1.33
1.905	1.37
2.188	1.36
2.512	1.35
2.884	1.37
3.311	1.41
3.802	1.47
4.365	1.54
5.012	1.62
5.754	1.71
6.607	1.82
7.586	1.95
8.710	2.07
10.000	2.17
11.482	

Size (μm)	Volume In %
11.482	2.22
13.183	2.20
15.136	2.12
17.378	2.00
19.953	1.85
22.909	1.74
26.303	1.70
30.200	1.79
34.674	2.04
39.811	2.46
45.709	3.02
52.481	3.67
60.256	4.33
69.183	4.89
79.433	5.28
91.201	5.41
104.713	5.26
120.226	

Size (μm)	Volume In %
120.226	4.81
138.038	4.13
158.489	3.29
181.970	2.39
208.930	1.55
239.883	0.83
275.423	0.33
316.228	0.08
363.078	0.03
416.869	0.21
478.630	0.54
549.541	0.89
630.957	1.20
724.436	1.40
831.764	1.26
954.993	0.00
1096.478	0.00
1258.925	

Size (μm)	Volume In %
1258.925	0.00
1445.440	0.00
1659.587	0.00
1905.461	0.00
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

Mastersizer 2000 E - [jangid]

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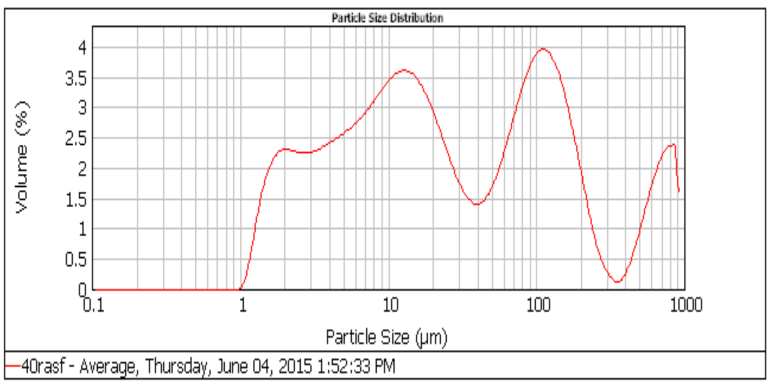
Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: 40rasf - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 1:52:33 PM	
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 1:52:34 PM	
Sample bulk lot ref:	**Result Source:** Averaged		
Particle Name: sludge	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.050	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 5.31 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.069 %	**Result Emulation:** Off
Concentration: 0.0065 %Vol	**Span :** 11.307	**Uniformity:** 4.71	**Result units:** Volume
Specific Surface Area: 0.736 m²/g	**Surface Weighted Mean D[3,2]:** 8.154 um	**Vol. Weighted Mean D[4,3]:** 106.629 um	

d(0.1): 2.572 um **d(0.5): 20.945 um** **d(0.9): 239.392 um**



Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %
0.010	0.00	0.105	0.00	1.096	0.49	11.482	3.24	120.226	3.44	1258.925	0.00
0.011	0.00	0.120	0.00	1.259	1.25	13.183	3.22	138.038	3.09	1445.440	0.00
0.013	0.00	0.138	0.00	1.445	1.75	15.136	3.08	158.489	2.55	1659.587	0.00
0.015	0.00	0.158	0.00	1.660	2.01	17.378	2.83	181.970	1.89	1905.461	0.00
0.017	0.00	0.182	0.00	1.905	2.08	19.953	2.49	208.930	1.23	2187.762	0.00
0.020	0.00	0.209	0.00	2.188	2.05	22.909	2.11	239.883	0.64	2511.886	0.00
0.023	0.00	0.240	0.00	2.512	2.03	26.303	1.74	275.423	0.30	2884.032	0.00
0.026	0.00	0.275	0.00	2.884	2.04	30.200	1.44	316.228	0.11	3311.311	0.00
0.030	0.00	0.316	0.00	3.311	2.10	34.674	1.28	363.078	0.18	3801.894	0.00
0.035	0.00	0.363	0.00	3.802	2.18	39.811	1.28	416.869	0.49	4365.158	0.00
0.040	0.00	0.417	0.00	4.365	2.27	45.709	1.46	478.630	0.96	5011.872	0.00
0.046	0.00	0.479	0.00	5.012	2.36	52.481	1.79	549.541	1.46	5754.399	0.00
0.052	0.00	0.550	0.00	5.754	2.47	60.256	2.24	630.957	1.88	6606.934	0.00
0.060	0.00	0.631	0.00	6.607	2.62	69.183	2.72	724.436	2.11	7585.776	0.00
0.069	0.00	0.724	0.00	7.586	2.81	79.433	3.15	831.764	1.87	8709.636	0.00
0.079	0.00	0.832	0.00	8.710	3.00	91.201	3.46	954.993	0.00	10000.000	
0.091	0.00	0.955	0.03	10.000	3.16	104.713	3.56	1096.478	0.00		
0.105		1.096		11.482		120.226		1258.925			

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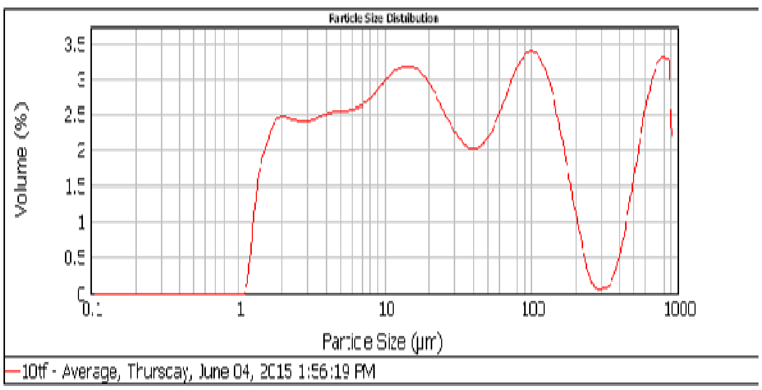
Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: 10tf - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 1:56:19 PM	
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 1:56:20 PM	
Sample bulk lot ref:	**Result Source:** Averaged		
Particle Name: sludge	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.050	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 6.01 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.463 %	**Result Emulation:** Off
Concentration: 0.0075 %Vol	**Span :** 24.104	**Uniformity:** 5.06	**Result units:** Volume
Specific Surface Area: 0.732 m²/g	**Surface Weighted Mean D[3,2]:** 8.197 um	**Vol. Weighted Mean D[4,3]:** 126.950 um	

d(0.1): 2.532 um **d(0.5): 23.460 um** **d(0.9): 568.021 um**



Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %	Size (μm)	Volume In %
0.010	0.00	0.105	0.00	1.096	0.15	11.482	2.82	120.226	2.76	1258.925	0.00
0.011	0.00	0.120	0.00	1.259	1.32	13.183	2.86	138.038	2.32	1445.440	0.00
0.013	0.00	0.138	0.00	1.445	1.81	15.136	2.84	158.489	1.77	1659.587	0.00
0.015	0.00	0.158	0.00	1.660	2.15	17.378	2.73	181.970	1.16	1905.461	0.00
0.017	0.00	0.182	0.00	1.905	2.23	19.953	2.57	208.930	0.59	2187.762	0.00
0.020	0.00	0.209	0.00	2.188	2.22	22.909	2.36	239.883	0.15	2511.886	0.00
0.023	0.00	0.240	0.00	2.512	2.17	26.303	2.14	275.423	0.06	2884.032	0.00
0.026	0.00	0.275	0.00	2.884	2.18	30.200	1.95	316.228	0.09	3311.311	0.00
0.030	0.00	0.316	0.00	3.311	2.22	34.674	1.84	363.078	0.37	3801.894	0.00
0.035	0.00	0.363	0.00	3.802	2.27	39.811	1.82	416.869	0.91	4365.158	0.00
0.040	0.00	0.417	0.00	4.365	2.30	45.709	1.92	478.630	1.57	5011.872	0.00
0.046	0.00	0.479	0.00	5.012	2.30	52.481	2.12	549.541	2.22	5754.399	0.00
0.052	0.00	0.550	0.00	5.754	2.31	60.256	2.39	630.957	2.73	6606.934	0.00
0.060	0.00	0.631	0.00	6.607	2.36	69.183	2.68	724.436	2.96	7585.776	0.00
0.069	0.00	0.724	0.00	7.586	2.45	79.433	2.93	831.764	2.57	8709.636	0.00
0.079	0.00	0.832	0.00	8.710	2.59	91.201	3.05	954.993	0.00	10000.000	
0.091	0.00	0.955	0.00	10.000	2.72	104.713	3.00	1096.478	0.00		
0.105		1.096		11.482		120.226		1258.925			

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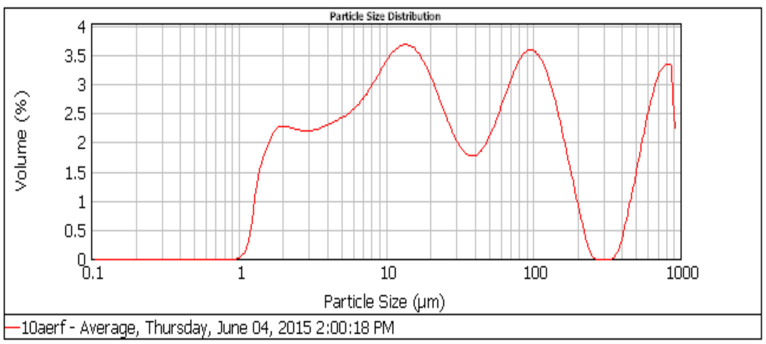
Current User: bn

Sieve ASTM E11 61 (M) | Result Statistics (M) | Parameter report (M) | Trend (M)

Records | Result Analysis (M) | Data (M) | Fit (M) | Result Difference (M) | Sieve BS 410 1986 - ISO565 1990 (M)

Sample Name: 10aerf - Average	**SOP Name:**	**Measured:** Thursday, June 04, 2015 2:00:18 PM	
Sample Source & type: Supplier	**Measured by:** bn	**Analysed:** Thursday, June 04, 2015 2:00:19 PM	
Sample bulk lot ref:	**Result Source:** Averaged		
Particle Name: sludge	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.050	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 6.40 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.273 %	**Result Emulation:** Off
Concentration: 0.0082 %Vol	**Span :** 25.814	**Uniformity:** 5.29	**Result units:** Volume
Specific Surface Area: 0.711 m²/g	**Surface Weighted Mean D[3,2]:** 8.433 um	**Vol. Weighted Mean D[4,3]:** 124.124 um	

d(0.1): 2.640 um **d(0.5): 21.904 um** **d(0.9): 568.069 um**



Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (μm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.00
0.240	0.00
0.275	0.00
0.316	0.00
0.363	0.00
0.417	0.00
0.479	0.00
0.550	0.00
0.631	0.00
0.724	0.00
0.832	0.00
0.955	0.02
1.096	

Size (μm)	Volume In %
1.096	0.27
1.259	1.22
1.445	1.70
1.660	1.99
1.905	2.06
2.188	2.02
2.512	1.98
2.884	1.98
3.311	2.02
3.802	2.08
4.365	2.15
5.012	2.22
5.754	2.33
6.607	2.49
7.586	2.70
8.710	2.94
10.000	3.15
11.482	

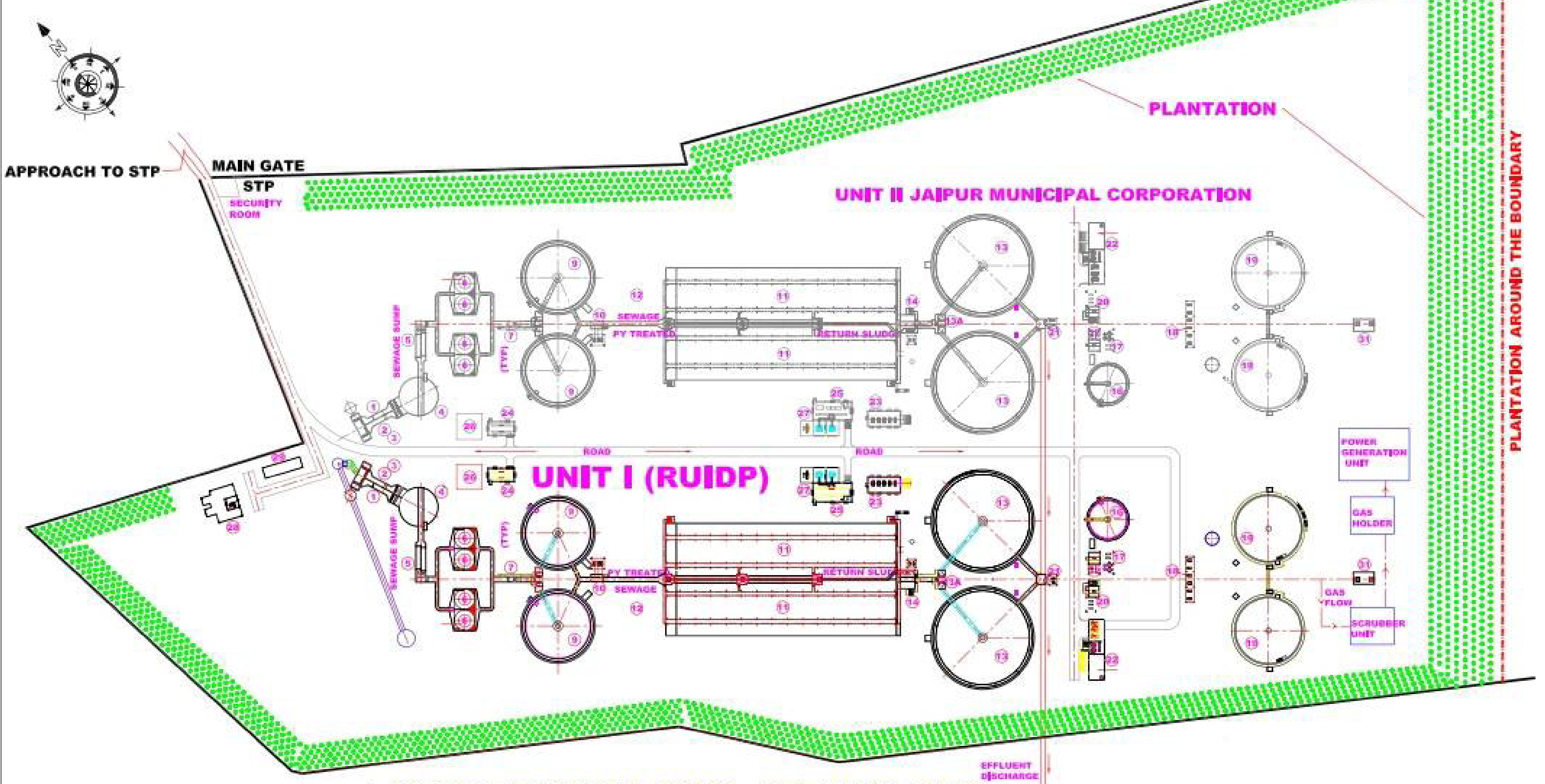
Size (μm)	Volume In %
11.482	3.29
13.183	3.31
15.136	3.22
17.378	3.00
19.953	2.69
22.909	2.33
26.303	1.98
30.200	1.72
34.674	1.60
39.811	1.63
45.709	1.83
52.481	2.15
60.256	2.53
69.183	2.90
79.433	3.16
91.201	3.24
104.713	3.11
120.226	

Size (μm)	Volume In %
120.226	2.77
138.038	2.26
158.489	1.64
181.970	0.99
208.930	0.41
239.883	0.00
275.423	0.00
316.228	0.00
363.078	0.20
416.869	0.78
478.630	1.47
549.541	2.15
630.957	2.70
724.436	2.99
831.764	2.61
954.993	0.00
1096.478	0.00
1258.925	

Size (μm)	Volume In %
1258.925	0.00
1445.440	0.00
1659.587	0.00
1905.461	0.00
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

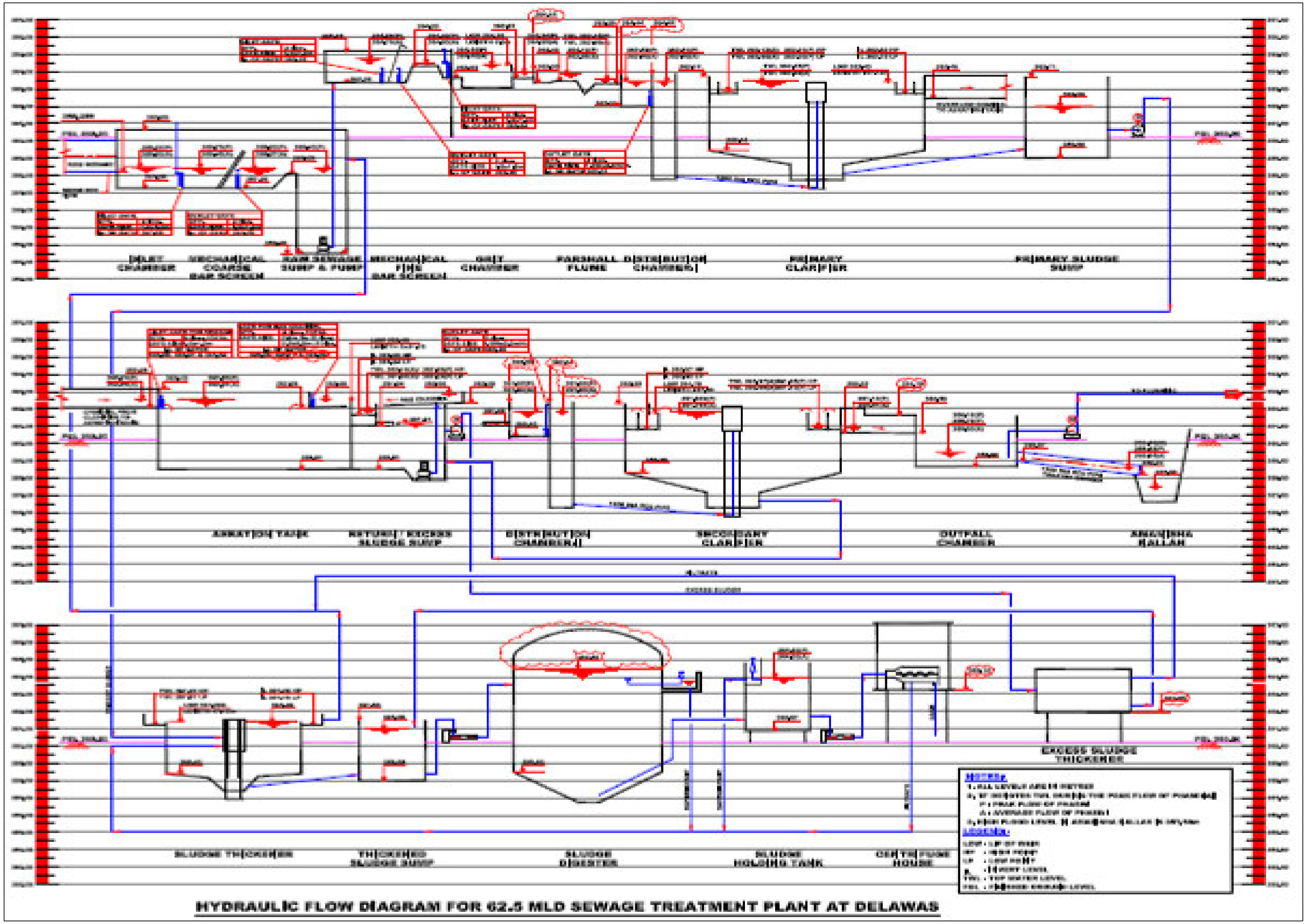
SIZES OF STP UNIT I

SL. No.	DESCRIPTION	QTY	SIZES IN METRES
1	INLET CHAMBER	1	7.0x3.1x1.61 LD
2	COARSE SCREEN CHAMBER-MECHANICAL	1	16.60x1.60x1.53 LD
3	COARSE SCREEN CHAMBER-MANUAL	1	16.60x1.60x1.44 LD
4	RAW SEWAGE SUMP	1	Ø15.0x4.91 LD
5	FINE SCREEN CHAMBER	2	10.0x1.60x1.5 LD
6	GRIT CHAMBER	4	8.0x8.0x0.8 SWD
7	PARSHAL FLUME	1	16.0x1.94x0.75 LD
8	DISTRIBUTION CHAMBER-I	1	2.6x9.64
9	PRIMARY CLARIFIER	2	Ø28.8x4.0 SWD
10	PRIMARY SLUDGE SUMP	1	4.5x2.6x3.0 LD
11	AERATION TANK	2	90.0x21.75x4.0 LD
12	ANOXIC TANK (FUTURE)	1	Area for future
13	SECONDARY CLARIFIER	2	Ø40.0x3.5 SWD
13A	DISTRIBUTION CHAMBER-II	1	2.6x7.3
14	RETURN / EXCESS SLUDGE SUMP	2	7.0x6.90x2.7 LD
15	SITE OFFICE	1	7.23x9.96
16	SLUDGE THICKENER	1	Ø15.0x3.0 SWD
17	DIGESTER FEED PUMP HOUSE	2	2.1x2.0
18	DIGESTER SLUDGE MIXING PUMP HOUSE	6	18.0x3.25
19	SLUDGE DIGESTER	2	Ø25.65x6.0 SWD
20	SLUDGE HOLDING TANK	1	4.0x4.0x3.13 LD
21	OUTLET CHAMBER WITH DELIVERY SUMP	1	3.5x3.5x1.5 SWD
22	CENTRIFUGE HOUSE	1	23.7x6.0 2 STOREYED
23	BLOWER ROOM	1	12.65x6.0x5.0
24	MCC ROOM	1	10.0x5.0
25	PMCC ROOM	1	15.0x7.0
26	OPEN STORE YARD	1	10.0x10.0
27	TRANSFORMER YARD	1	15.0x6.0
28	ADMINISTRATION BLOCK	1	12.77x13.49 (STORE)
29	PARKING SHED	1	15.0x4.0
30	SECURITY ROOM	1	3.0x3.6
31	GAS BURNER THICKENED SLUDGE SUMP	1 1	8.0x4.5 4.3x4.3x3.0 LD



LAY OUT OF 62.50 MLD STP DELAWAS JAIPUR

Hydraulic Flow diagram of 62.50 MLD STP Delawas ,Jaipur

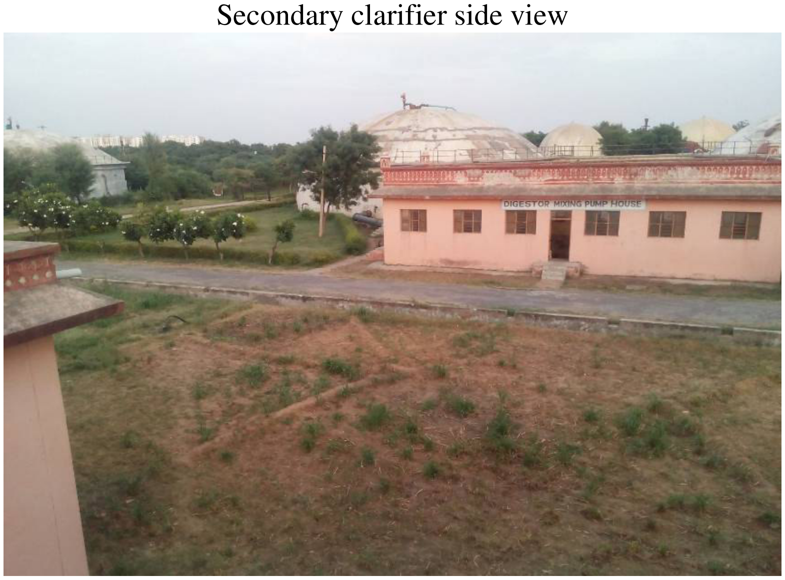


Fine screen overview

STP overview from Parshall Flume

Inlet side view

Secondary clarifier side view



Sludge handling side view

Appendix 3 – Observed and calculated values with addition of various sludge in various volume

Addition of return/excess sludge (STP Delawas) in various volumes										
Parameters	Observed values for		Observed value	Calculated values for	Observed value l	Calculated values for	Observed value	Calculated values for	Observed value	Calculated values for
	Only Raw sewage	Raw sewage + sludge (Immediate after addition)	After 30 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.	After 60 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.	After 90 min	Raw sewage + sludge (assumed to be arriving at aeration tank.	After 120 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.
With 10 mL Sludge										
TSS (mg/lit)	496.0	567.8	380.0	304.5	252.0	284.7	242.0	280.7	234.0	270.8
COD (mg/lit.)	688.0	697.3	485.0	398.3	396.0	380.5	380.0	368.6	376.0	348.8
BOD_5 (mg/lit.)	285.0	287.0	237.0	181.4	186.0	170.5	166.0	168.5	165.0	167.5
Filtered BOD_5	83.0	89.9	84.0	79.9	78.0	74.9	75.0	72.9	71.0	64.0
With 20 mL Sludge										
TSS (mg/lit)	496	638	298	377	256	358	246	354	242	344
COD (mg/lit.)	688	706	465	410	424	393	406	381	404	361
BOD_5 (mg/lit.)	285	292	228	186	194	175	168	173	164	172
Filtered BOD	83.0	85	84	81	78	76	72	74	69	65
With 30 mL Sludge										
TSS (mg/lit)	496	707	318	449	301	430	282	426	245	416
COD (mg/lit.)	688	715	504	422	403	405	401	393	398	374
BOD_5 (mg/lit.)	285	295	238	190	210	179	169	177	158	176
Filtered BOD	83	85	83	82	81	77	73	75	65	75
With 40 mL Sludge										
TSS (mg/lit)	496	775	336	519	308	500	285	496	252	487
COD (mg/lit.)	688	724	395	434	409	417	419	405	414	386
BOD_5 (mg/lit.)	285	298	250	194	214	183	202	181	169	181
Filtered BOD	83	86	85	82	84	78	79	76	69	67
With 50 mL Sludge										
TSS (mg/lit)	496	841	356	588	328	569	288	565	268	556
COD (mg/lit.)	688	733	405	445	485	428	421	417	416	398
BOD_5 (mg/lit.)	285	301	292	198	216	188	188	186	176	185
Filtered BOD	83	87	85	83	81	78	78	76	72	68

Addition of thickened return/ excess sludge (STP Delawas) in various volumes										
Parameters	Observed values for		Observed value	Calculated values for	Observed value l	Calculated values for	Observed value	Calculated values for	Observed value	Calculated values for
	Only Raw sewage	Raw sewage + sludge (Immediate after addition)	After 30 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.	After 60 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.	After 90 min	Raw sewage + sludge (assumed to be arriving at aeration tank.	After 120 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.
With 10 mL Sludge										
TSS (mg/lit)	576.0	855.0	322.0	527.3	320.0	508.5	268.0	500.6	219.0	483.7
COD (mg/lit.)	768.0	831.0	494.0	469.6	417.0	446.8	385.0	434.9	356.0	416.1
BOD_5 (mg/lit.)	300.0	305.2	256.0	191.3	186.0	178.5	170.0	173.5	168.0	169.5
Filtered BOD_5	89.0	89.0	84.0	81.6	74.0	74.7	69.0	71.7	68.0	67.7
With 20 mL Sludge										
TSS (mg/lit)	576.0	1128.5	356.0	804.0	341.0	785.4	276.0	777.6	232.0	760.9
COD (mg/lit.)	768.0	894.6	502.0	535.8	424.0	514.2	392.0	501.5	372.0	482.9
BOD_5 (mg/lit.)	300.0	310.3	269.0	197.5	189.0	184.8	174.0	179.9	172.0	177.0
Filtered BOD	89.0	90.0	86.0	82.2	76.0	76.3	72.0	72.4	69.0	68.5
With 30 mL Sludge										
TSS (mg/lit)	576.0	1396.8	360.0	1075.4	352.0	1057.0	279.0	1049.2	250.0	1032.7
COD (mg/lit.)	768.0	956.1	490.0	600.8	432.0	579.4	402.0	566.8	376.0	548.3
BOD_5 (mg/lit.)	300.0	315.3	283.0	203.6	201.0	191.0	178.0	186.2	187.0	183.3
Filtered BOD	89.0	90.5	87.0	82.8	83.0	77.0	75.0	73.1	70.0	73.1
With 40 mL Sludge										
TSS (mg/lit)	576.0	1659.8	372.0	1341.6	356.0	1323.3	283.0	1315.6	252.0	1299.3
COD (mg/lit.)	768.0	1016.4	506.0	664.5	438.0	643.3	388.0	630.8	428.0	612.5
BOD_5 (mg/lit.)	300.0	320.2	287.0	209.6	204.0	197.1	196.0	192.3	201.0	189.4
Filtered BOD	89.0	91.0	91.0	83.3	86.0	77.6	78.0	73.7	73.0	69.9
With 50 mL Sludge										
TSS (mg/lit)	576.0	1917.9	380.0	1602.7	361.0	1584.6	286.0	1577.0	254.0	1560.8
COD (mg/lit.)	768.0	1075.5	513.0	727.0	443.0	706.0	392.0	693.6	452.0	675.5
BOD_5 (mg/lit.)	300.0	325.0	291.0	215.5	210.0	203.1	216.0	198.3	210.0	195.5
Filtered BOD	89.0	91.5	93.0	83.9	89.0	78.2	81.0	74.4	86.0	70.6

Addition of anaerobic digested sludge (STP Delawas) in various volumes										
Parameters	**Observed values for**		**Observed value**	**Calculated values for**	**Observed value l**	**Calculated values for**	**Observed value**	**Calculated values for**	**Observed value**	**Calculated values for**
	Only Raw sewage	**Raw sewage + sludge (Immediate after addition)**	**After 30 min**	**Raw sewage+ sludge (assumed to be arriving at aeration tank.**	**After 60 min**	**Raw sewage+ sludge (assumed to be arriving at aeration tank.**	**After 90 min**	**Raw sewage + sludge (assumed to be arriving at aeration tank.**	**After 120 min**	**Raw sewage+ sludge (assumed to be arriving at aeration tank.**
With 10 mL Sludge										
TSS (mg/lit)	524.0	700.2	674.0	409.6	392.0	399.7	385.0	385.9	380.0	382.9
COD (mg/lit.)	680.0	690.4	506.0	405.2	670.0	384.4	620.0	373.5	506.0	353.7
BOD_5 (mg/lit.)	288.0	291.2	261.0	187.2	192.0	174.4	175.0	168.4	165.0	166.4
Filtered BOD_5	81.0	81.9	86.0	80.9	82.0	76.9	69.0	74.0	65.0	66.0
With 20 mL Sludge										
TSS (mg/lit)	524.0	873.0	416.0	585.7	409.0	575.9	401.0	562.2	378.0	559.3
COD (mg/lit.)	680.0	700.5	686.0	418.2	671.0	397.6	639.0	386.8	639.0	367.2
BOD_5 (mg/lit.)	288.0	294.3	228.0	191.4	189.0	178.6	182.0	172.7	172.0	170.8
Filtered BOD	81.0	82.8	87.0	81.8	85.0	77.9	76.0	74.9	68.0	67.1
With 30 mL Sludge										
TSS (mg/lit)	524.0	1043.8	432.0	758.4	431.0	748.7	409.0	735.1	386.0	732.2
COD (mg/lit.)	680.0	710.5	692.0	430.9	681.0	410.5	674.0	399.8	641.0	380.4
BOD_5 (mg/lit.)	288.0	297.4	232.0	195.4	197.0	182.8	189.0	177.0	181.0	175.0
Filtered BOD	81.0	83.6	89.0	82.7	86.0	78.8	76.0	75.9	75.0	75.9
With 40 mL Sludge										
TSS (mg/lit)	524.0	1210.5	541.0	927.8	518.0	918.2	412.0	904.7	393.0	901.8
COD (mg/lit.)	680.0	720.3	692.0	443.4	652.0	423.2	645.0	412.6	641.0	393.4
BOD_5 (mg/lit.)	288.0	300.4	239.0	199.4	204.0	186.9	196.0	181.2	186.0	179.2
Filtered BOD	81.0	84.5	85.0	83.5	81.0	79.7	78.0	76.8	76.0	69.1
With 50 mL Sludge										
TSS (mg/lit)	524.0	1373.9	456.0	1093.9	520.0	1084.4	415.0	1071.0	397.0	1068.2
COD (mg/lit.)	680.0	729.9	670.0	455.6	658.0	435.6	650.0	425.1	641.0	406.1
BOD_5 (mg/lit.)	288.0	303.3	241.0	203.3	205.0	191.0	197.0	185.2	190.0	183.3
Filtered BOD	81.0	85.3	88.0	84.3	83.0	80.5	81.0	77.7	77.0	70.0

Addition of return sludge (27 MLD- extended aeration process) in various volumes										
Parameters	**Observed values for**		**Observed value**	**Calculated values for**	**Observed value l**	**Calculated values for**	**Observed value**	**Calculated values for**	**Observed value**	**Calculated values for**
	Only Raw sewage	**Raw sewage + sludge (Immediate after addition)**	**After 30 min**	**Raw sewage+ sludge (assumed to be arriving at aeration tank.**	**After 60 min**	**Raw sewage+ sludge (assumed to be arriving at aeration tank.**	**After 90 min**	**Raw sewage + sludge (assumed to be arriving at aeration tank.**	**After 120 min**	**Raw sewage+ sludge (assumed to be arriving at aeration tank.**
With 10 mL Sludge										
TSS (mg/lit)	510.0	751.8	385.0	480.6	280.0	244.6	248.0	212.8	198.0	197.5
COD (mg/lit.)	654.0	678.3	502.0	416.9	430.0	398.1	365.0	384.2	330.0	365.4
BOD_5 (mg/lit.)	293.0	295.9	209.0	188.0	206.0	174.2	164.0	170.2	165.0	168.2
Filtered BOD_5	82.0	82.6	81.0	80.6	77.0	76.7	65.0	73.7	62.0	65.8
With 20 mL Sludge										
TSS (mg/lit)	510.0	988.9	390.0	720.3	256.0	700.7	246.0	693.8	242.0	683.1
COD (mg/lit.)	654.0	702.0	532.0	443.2	424.0	424.6	406.0	410.9	404.0	392.2
BOD_5 (mg/lit.)	293.0	298.8	240.0	192.0	194.0	178.2	192.0	174.3	190.0	172.4
Filtered BOD	82.0	83.2	86.0	81.3	78.0	77.4	74.0	74.4	69.1	66.6
With 30 mL Sludge										
TSS (mg/lit)	510.0	1221.4	394.0	955.4	308.0	936.0	256.0	929.2	207.0	918.5
COD (mg/lit.)	654.0	725.4	512.0	469.0	476.0	450.6	385.0	437.0	341.0	418.6
BOD_5 (mg/lit.)	293.0	301.7	228.0	199.6	205.0	182.2	174.0	178.3	172.0	176.4
Filtered BOD	82.0	83.8	82.0	81.9	81.0	78.0	72.0	75.1	67.0	67.3
With 40 mL Sludge										
TSS (mg/lit)	510.0	1449.5	405.0	1186.0	312.0	1166.8	260.0	1160.0	211.0	1149.5
COD (mg/lit.)	654.0	748.2	519.0	494.4	482.0	476.1	394.0	462.7	348.0	444.4
BOD_5 (mg/lit.)	293.0	304.4	235.0	199.6	209.0	182.3	182.0	182.3	178.0	180.4
Filtered BOD	82.0	84.4	82.0	82.5	81.0	79.0	72.0	75.8	69.0	68.1
With 50 mL Sludge										
TSS (mg/lit)	510.0	1673	410	1412.2	316	1393.1	264	1386.5	216	1376.0
COD (mg/lit.)	654.0	771	523	519.2	486	501.1	402	487.8	352	469.7
BOD_5 (mg/lit.)	293.0	307	238	203.3	212	190.0	188	186.2	182	184.3
Filtered BOD	82.0	85	83	83.1	82	79.3	74	76.4	71	68.8

Addition of aerobically digested sludge (27 MLD- extended aeration process) in various volumes										
Parameters	Observed values for		Observed value	Calculated values for	Observed value l	Calculated values for	Observed value	Calculated values for	Observed value	Calculated values for
	Only Raw sewage	Raw sewage + sludge (Immediate after addition)	After 30 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.	After 60 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.	After 90 min	Raw sewage + sludge (assumed to be arriving at aeration tank.	After 120 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.
With 10 mL Sludge										
TSS (mg/lit)	514	805.0	391.0	529.7	225.0	243.6	251.0	210.2	195.0	495.0
COD (mg/lit.)	692	716.8	514.0	423.8	434.0	400.0	371.0	382.2	330.0	366.3
BOD_5 (mg/lit.)	287	289.5	224.0	184.5	206.0	170.6	165.0	166.7	153.0	165.7
Filtered BOD_5	82	82.5	79.0	78.5	77.0	75.5	62.0	72.6	58.0	64.7
With 20 mL Sludge										
TSS (mg/lit)	514	1090.2	397.0	817.6	295.0	796.1	260.0	789.2	240.0	783.3
COD (mg/lit.)	692	741.2	524.0	451.0	440.0	427.5	381.0	409.8	356.0	394.1
BOD_5 (mg/lit.)	287	291.9	234.0	187.9	213.0	174.2	197.0	170.3	167.0	169.3
Filtered BOD	82	82.9	81.0	79.0	78.0	76.1	72.0	73.1	61.0	65.3
With 30 mL Sludge										
TSS (mg/lit)	514	1369.9	402.0	1100.0	308.0	1078.6	249.0	1071.8	244.0	1066.0
COD (mg/lit.)	692	765.0	532.0	477.7	476.0	454.4	432.0	436.9	413.0	421.4
BOD_5 (mg/lit.)	287	294.2	239.0	191.3	205.0	177.7	198.0	173.8	191.0	172.9
Filtered BOD	82	83.4	82.0	79.5	81.0	76.6	74.0	73.7	68.0	65.9
With 40 mL Sludge										
TSS (mg/lit)	514	1644	406	1376.9	310	1355.8	252	1349.0	249	1343.3
COD (mg/lit.)	692	788	536	503.8	480	480.8	436	463.5	416	448.1
BOD_5 (mg/lit.)	287	297	241	194.6	206	181.2	201	177.3	196	176.3
Filtered BOD	82	84	83	80.0	82	77.1	76	74.2	71	66.5
With 50 mL Sludge										
TSS (mg/lit)	514	1913	411	1648.6	314	1627.6	260	1621.0	252	1615.2
COD (mg/lit.)	692	811	540	529.5	483	506.7	438	489.5	418	474.3
BOD_5 (mg/lit.)	287	299	245	197.9	210	184.5	204	180.7	198	179.8
Filtered BOD	82	84	83	80.5	83	77.6	77	74.8	72	67.1

Addition of brief aerated thickened return/excess sludge (STP Delawas) in various volumes										
Parameters	**Observed values for**		**Observed value**	**Calculated values for**	**Observed value l**	**Calculated values for**	**Observed value**	**Calculated values for**	**Observed value**	**Calculated values for**
	Only Raw sewage	**Raw sewage + sludge (Immediate after addition)**	**After 30 min**	**Raw sewage+ sludge (assumed to be arriving at aeration tank.**	**After 60 min**	**Raw sewage+ sludge (assumed to be arriving at aeration tank.**	**After 90 min**	**Raw sewage + sludge (assumed to be arriving at aeration tank.**	**After 120 min**	**Raw sewage+ sludge (assumed to be arriving at aeration tank.**
With 10 mL Sludge										
TSS (mg/lit)	498.0	769.2	294.0	505.8	266.0	488.0	224.0	480.1	201.0	466.2
COD (mg/lit.)	694.0	703.0	468.0	403.0	396.0	384.2	360.0	370.3	328.0	345.6
BOD_5 (mg/lit.)	286.0	287.7	239.0	180.8	170.0	167.9	160.0	163.0	151.0	161.0
Filtered BOD_5	84.0	84.4	81.0	79.4	71.0	74.5	58.0	71.5	54.0	63.6
With 20 mL Sludge										
TSS (mg/lit)	498.0	1035.1	299.0	774.3	302.0	756.7	251.0	748.8	248.0	735.1
COD (mg/lit.)	694.0	713.8	474.0	415.7	428.0	397.1	412.0	383.4	410.0	358.9
BOD_5 (mg/lit.)	286.0	289.4	241.0	183.5	195.0	170.8	193.0	165.9	191.0	163.9
Filtered BOD	84.0	84.7	82.0	79.8	79.0	74.9	71.0	72.0	66.0	64.2
With 30 mL Sludge										
TSS (mg/lit)	498.0	1295.8	312.0	1037.6	315.0	1020.1	261.0	1012.3	252.0	998.7
COD (mg/lit.)	694.0	723.4	489.0	428.2	436.0	409.8	416.0	396.2	418.0	371.9
BOD_5 (mg/lit.)	286.0	291.1	245.0	186.2	198.0	173.6	195.0	168.7	196.0	166.8
Filtered BOD	84.0	85.1	83.0	80.3	81.0	75.4	74.0	72.5	69.0	64.7
With 40 mL Sludge										
TSS (mg/lit)	498.0	1551.0	318.0	1295.8	321.0	1278.5	264.0	1270.8	254.0	1257.3
COD (mg/lit.)	694.0	732.8	496.0	440.5	446.0	422.2	419.0	408.8	426.0	384.7
BOD_5 (mg/lit.)	286.0	292.7	253.0	188.8	206.0	176.3	198.0	171.5	200.0	169.6
Filtered BOD	84.0	85.5	84.0	80.7	82.0	75.8	74.0	73.0	71.0	65.3
With 50 mL Sludge										
TSS (mg/lit)	498.0	1802.4	320.0	1549.0	328.0	1531.9	270.0	1524.3	256.0	1511.0
COD (mg/lit.)	694.0	742.0	501.0	452.5	452.0	434.4	422.0	421.1	428.0	397.3
BOD_5 (mg/lit.)	286.0	294.3	259.0	191.4	214.0	179.0	208.0	174.3	203.0	172.4
Filtered BOD	84.0	85.8	84.0	81.0	83.0	76.3	76.0	73.4	75.0	65.8

LIST OF PAPERS PUBLISHED IN NATIONAL/INTERNATIONAL JOURNALS

Energy Conservation and Recovery from 62.50 MLD Sewage Treatment Plant of Delawas, Jaipur-A Case Study

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ABSTRACT

In order to cater to the growing health needs of the population of Jaipur city, Rajasthan Urban Infrastructure Development Project (RUIDP) has commissioned a 62.50 MLD STP at Delawas, Jaipur based on conventional activated sludge process using diffused aeration system. Power consumption accounts for almost 75% of the expenditure on O&M of the plant. The per day power consumption for operation of STP is 8576 Kwh, which presently amounts to a total of about Rs 12-13 lac per month. Many energy saving measures have been taken for the plant operation that have resulted in substantial saving in the energy costs. Variable Frequency Drive (VFD) has been provided for the first time in Rajasthan. Man Machine Interface (MMI) is provided through Programmable Logic Control System (PLC). For sludge handling anaerobic sludge digesters have been constructed. The main constituents of the biogas produced are CH_4 60-70%, CO_2-5-10%, N_2-10-15% and H_2S up to 1%. Presently average biogas production is about 5800-6500 Nm^3 per day which is being flaring presently. The methane component can result in generation of approximately 9500 Kwh on daily basis, which can make the STP self sufficient in terms of power requirements. Apart from above, the treated effluent can also be re-used for agriculture, forestation, and groundwater recharge or pasture development without further treatment. This would further result in savings of power as pumping of groundwater from deep strata will be reduced. The present paper is an attempt to assess the energy balances of the STP.

INTRODUCTION

Sewage treatment is a significant user of energy. Operation of pumps, blowers and other equipment at a typical sewage treatment plant requires an annual electrical energy consumption of about 50 kWh per person. Thus, substantial amounts of energy are required to treat sewage from major population areas, and sewage treatment often comprises the largest use of electricity by local governments. Conventional sewage treatment plants remove organic content from the water stream by reacting the proteins, fats and carbohydrates with oxygen from the air. This oxidation process is undertaken at ambient temperature by aerobic bacteria and converts most of the organic material to carbon dioxide and water. The process also produces sewage sludge, or bio-solids, consisting of un-oxidized organic matter and bacterial cells. Some treatment plants further reduce the quantity of bio-solids through an anaerobic treatment process. Here, in the absence of air, other types of bacteria digest the bio-solids, producing "biogas", a mixture of methane and carbon dioxide. Methane is the main component of natural gas, and the biogas produced, can be burned in an engine or turbine to produce power and generate electricity. In this way, anaerobic treatment can generate electrical energy used in the sewage treatment plant.

The possibility of biologically recovering energy in the form of the combustible gas, methane, has prompted an interest in applying bio-gasification to waste water treatment by digestion of primary & secondary excess sludge in anaerobic condition in air tight container in developed and developing countries alike. The attraction to the concept arises from the fact that bio-gasification in Wastewater Treatment can make the STP self sufficient in terms of power requirements. The operating costs for low efficiency Plant and equipment can be substantially higher than the operating costs for high efficiency Plant and equipment, and that the cost differential over the ten year period used in calculation make, in all probability, greatly exceed any incremental capital cost savings which may be realized by offering lower efficiency Plant. Therefore Bidders were encouraged to offer Plant and equipment which has high efficiencies at the specified operating conditions. The present case study shows an evaluation of energy balances considering the electricity generation potential from digester gases, introduction of improved and efficient machinery (VFD), and indirect savings of energy from STP at Delawas, Jaipur.

CASE STUDY

Rajasthan Urban Infrastructure Development Project (RUIDP) has commissioned 62.50 MLD STP at Delawas Jaipur. RUIDP constructed & commissioned the STP in Year 2006. Considering the life cycle cost of O&M, weightage was given to efficient system that optimizes the capitalized cost for 10 years at 10% discounting. This made a major difference in total cost of work including O&M.

LAY OUT OF STP

Figure -1 shows the general Lay out of STP & figure -2 shows the sewerage coverage area of south zone of Jaipur city. The farthest point is about 25 Km from STP & nearest is 1 Km. from STP. There is no pumping in sewerage network laid up to STP.

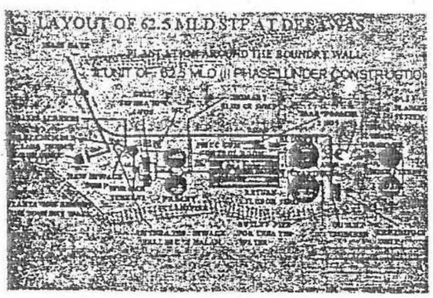

Fig.1 General layout of STP

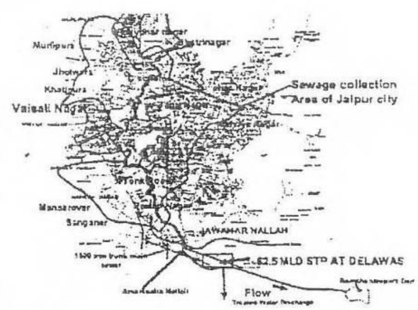

Fig-2-sewerage coverage area south Jaipur

Main sewer reaching at STP site is 1800 mm diameter. This main sewer caters the sewage/ wastewater of south zone of Jaipur starting from Vidhyadhar Nagar to Pratap Nagar Sanganer as shown on fig.2 above.

SALIENT FEATURES OF STP

The plant is based on conventional activated sludge process having diffused aeration system. Sludge is being handled in anaerobic digesters. Digested sludge from Digester is being pumped to centrifuge unit where it is being converted to semi solid form having consistency of 22% solids, which is subsequently sold as manure. The produced gases presently are being flared which have a potential to generate all the electricity required to operate the plant. The STP was commissioned with the full designed plant capacity flow of 62.50 MLD. The total guaranteed power consumption is 8576 KWH/ day for treatment of 62.5-63 MLD sewage & daily consumption is about 7950-8400 KWH/day. The salient features of STP are given below in Table 1.

Table 1: Salient Features of 62.50 MLD STP

S. No.	Particulars	Details
1.	Capacity: Present I Phase	62.50 MLD
2.	Work cost	Total Rs. 1157.00 lacs in year 2004-05. O&M cost for 5 years is Rs 180 lacs for 5 year O&M
3.	Total land area	Total 28 Hectare, STP constructed in 7.50 Hectare. Remaining area for future expansion.
4.	Process	Activated Sludge Process with anaerobic Digester & centrifuge unit (no sludge drying beds)
5.	Size of main sewer at STP	1800 mm
6.	Design flow on main sewer	Total 125 MLD
7.	Flow	At commissioning stage (2005-06) - 62-65 MLD. **Present -82-90 MLD**

EXCEPTIONAL FEATURES OF STP

To save power, a Variable Frequency Drive (VFD) is provided which is governed through programmed feed back circuit based on Dissolved Oxygen (DO) levels maintained in the bulk aeration reactor. DO analyzer is connected to VFD through Programmable Logic Control System (PLC). The VFD is controlled by signals generated by the DO Analyzers, in proportion to the dissolved oxygen content in the mixed liquor exiting the aeration tank compartments. The blowers fitted with VFD maintain the required dissolved oxygen concentration in the aeration through effective control of airflow rate resuting in huge savings in the aeration process. This is being used first time in Rajasthan. The air in aeration tank is being provided through the retrievable type membrane diffusers, placed at the floor level, spanning the entire floor area, for uniform distribution of air. A separate excess Sludge Thickener machine is provided to handle the excess activated sludge. Man Machine Interface (MMI) is through PLC controlling all processes except Gates, some valves & FM ratio. Presently the average incoming flow at STP Delwas is approximately 80-90 MLD. Designed capacity of STP is 62.50 MLD. STP is made functional and treatment of an average of 62.5-63 MLD is being done presently with the excess sewage bypassed. The sludge handling units are functioning on full designed capacity.

OPERATION & MAINTENANCE COST

Operation & Maintenance for 5 years of STP is with the same Contractor who has constructed the STP. Power Guarantee given for 8576KWH/day has been given by the contractor during the complete O&M period of 5 years. O&M cost includes the cost of Manpower, wear & tear of machinery, chemicals & maintenance of green belt in the campus comprising about 5000 plants. O&M expenditure of STP is given in Table 2.

Table 2: Operation and Maintenance Cost of STP

O & M Charges of Plant	Rs. Cost per month		
For	Power charges being/to be paid to JVVNL/Month	O&M cost being paid / to be paid to contractor/ Month	Total O&M Cost
I year(2006-07)	13.50-14.00 lacs (paid)	2.66 lacs(paid)	16.16-16.66 lacs
II year(2007-08)	14.00-15.00 lacs (paid)	2.82 lacs(paid)	16.82-17.82 lacs
III year(2008-09)	15.00-16.00 lacs (paid up to Oct-08)	2.98 lacs (paid up to Oct-08)	17.98-18.98 lacs
IV year(2009-10)	16.00-17.50 lacs	3.16 lacs	19.61-20.66 lacs
V year(2010-11)	17.50-19.00 lacs	3.36 lacs	20.86-22.36 lacs

Note- Price escalation is also being paid as per condition according to RBI Index.

The operating cost is about Rs. 26000-28000 per MLD sewage treatment up to secondary level treatment, which is less than that of most of ASP plants due to saving in power as shown above.

CHARACTERISTICS OF SEWAGE

Characteristics of raw and treated wastewater at STP are given in Table 3.

Table 3 : Characteristics of raw and treated sewage

Parameters	Raw Sewage parameters	Treated Sewage designed parameters	Monitored values of treated wastewater
BOD	Up to 300 mg/lit	30 mg/lit or less	18-30 mg/lit
COD	Up to 700 mg/lit	250 mg/lit or less	160-230mg/lit
Suspended solids	Up to 600 mg/lit	100 mg/lit or less	40-95 mg/lit
pH	7.2 to 7.9	6 to 9	7.2-7.9
Ammonnical Nitrogen	Up to 35 mg/lit	No treatment, if required space provided.	-
Total Nitrogen	Up to 55 mg/lit	-do-	-
Total Phosphates	Up to 16 mg/lit	-do-	-
TDS	Up to 1500 mg/lit	No treatment	-

The Plant is functioning satisfactorily except when colored wastewater (from adjoining printing/ textile Industries of Sangner) is received. The BOD to COD ratio changes & it affects adversely the biological oxidation.

ENERGY CONSERVATION AND RECOVERY FROM STP

Power consumption accounts for almost 75% of the expenditure on O&M of the plant. The per day power consumption for operation of STP is 8576 Kwh, which presently amounts to a total of about Rs 12-13 lac per month. Many energy saving measures have been taken for the plant operation resulting in substantial saving in the energy costs as stated above. For sludge handling anaerobic sludge digesters have been constructed & commissioned.

ESTIMATION OF GAS GENERATION

During digestion of primary & excess sludge of secondary clarifier in anaerobic digesters, the gases produced are mainly CH_4, CO_2, N_2 & H_2S. It is estimated that 1Kg of organic matter may produce about 0 .5 cum biogas. One Ncum biogas has calorific value of 21 MJ (1 MJ=0.27 Kw). Thus the estimated total Gas Production for 62.5 MLD may be about 357.9 cum/Hr considering BOD of average 270 mg/lit. Presently average biogas production is about 5800-6500 Nm^3 per day which is being flared in the absence of an energy conversion device. The main constituents of the biogas produced are CH_4 60-70%, CO_2- 5-10%, N_2-10-15% and H_2S up to 1%. The methane component can result in generation of huge power on daily basis, which can make the STP self sufficient in terms of power requirements. The test results of gases produced are given in Table 4.

Table 4: Characteristics of biogas produced during sludge digestion

Per day sludge generation					55-60 m3/day
gas generated during anaerobic digestion					5800-6200 Nm3/ day
The Characteristic & Calorific value of produced gases	Methane (CH_4) %v/v	CO_2	H2S	Calorific value Kcal/M^3	Samples were collected & tested in November 2006 at Laboratory of Shriram Institute New Delh.
Morning Sample no.1	52.2	35.00	1.02	5025	
Mid day Sample tested no.2	57.5	30.00	1.26	5613	
After noon Sample no.3	54.8	35.00	1.07	5279	
Protocol/ Method Followed	GC-FID	Orsat Appratus	IS-11255	IS- 14504	

Source- RUIDP Jaipur

POWER GENERATION FROM PRODUCED GASES

Presently about 6000 Nm3/day Bio gas is being produced at 62.50 STP at Delawas having 52-57% of methane. The calorific value of produced gases is 5000-5200 Kcal/M^3. Thus this gas can be used to run the gas Engine & through generator electricity can be produced The generated electricity may not only compensate the electricity requirement for running the main treatment plant but also save the electricity which can be utilized for some other purposes by the State

FLOW SCHEME FOR POWER GENERATION

Flow diagram for power generation is shown in Fig 3.

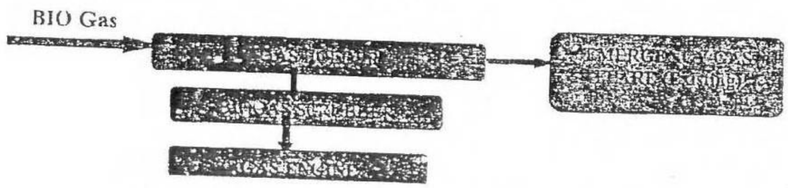

Fig. 3- Flow Diagram for power generation process

Assuming an overall Efficiency of Engine as 25%, the power generation may be = 526.12 Kw (adopting generator Eff. 95%). Terminal Power out put may be 470 KWH/day (9600 units/day). This can meet about 60% of the power requirement of the STP. Power generation system will depend on Calorific value of produced Gases in the digester. Estimation of gases produced in given in able 5 below:-

Table 5: Details of energy conversion from bio gas generated from the digester

ITEM	VALUE
Amount of Gas Generated From One 62.5 Mld Plant	6000 M3/DAY 250 M3/hr
Calorific Value of Gas	5000 TO 5600 KCAL/M3
Total Heat Energy of Gas	1300000 KCAL/hr
Total energy in kw hour	1509.3
Efficiency of power Generation unit iengine and generator	28 %
Electrical Energy that can Be Produced	400 KWH (9600 unit/day)

Power can be generated from bio gas from following machines
(i) Dual fuel engine
(ii) Gas turbine
(iii) Gas engine

Gas engine is the most suitable and efficient for present application among above options as the Gas Turbine is not used for Bio Gas Fuel since it is not suitable for such low capacity, and Dual fuel engine is used in remote areas where normal power supply is not available or is erratic. The gas engine can be run either with diesel or with biogas & diesel combination. Dual fuel engine needs more maintenance and diesel storage.

COST VIABILITY OF POWER GENERATION PLANT

Estimated cost of system to generate Terminal Power out put of 9500 KWH/day is Rs.750 lacs. Annual maintenance cost has been considered @ 5-5.5% of total capital cost of Rs. 750 lacs. Thus expenses for running the plant per KWH will be Rs. 2.50. Present Purchase cost of Power is Rs. 6.00 per KWH, thus saving for power generation in a year may be of the order of Rs.100 lacs (considering guaranteed power per day consumption of 8576 KWh to run the STP). Pay Back Period will be about 6-7 year. If standby unit is not provided then the pay back period will be about 5 years. Cost viability calculations are given in Table 6. The per KWH cost of electricity is taken as Rs.6.30 for 1st year & Rs. 6.90, Rs 7.6,Rs. 8.3, Rs 9.20 , Rs. 10.10 , Rs.11.10, Rs. 12.20, Rs. 13.40, Rs.14.70 for subsequent years up to 10 years period.

Table 6: Cost viability calculations

Cost Rs. in Lacs.

Year	Project execution cost	O&M cost /year	Cumulative cost /year	Cumulative interest (@ 15% per year)	Total Exp./ year	Cost of power to be generated /year	Saving/ year
1	2	3	4	5	6=(4+5)	7	8=(6-7)
2008	750.00	30.00	780.00	117.00	897.00	216.71	-680.28
2009	0	30.00	810.00	238.50	1048.50	476.78	-571.71
2010	0	36.00	846.00	365.40	1211.40	786.68	-424.71
2011	0	42.00	888.00	498.60	1386.60	1153.81	-232.78
2012	0	42.00	930.00	638.10	1568.10	1586.48	18.38
2013	0	48.00	978.00	784.80	1762.80	2094.16	331.36
2014	0	48.00	1026.00	938.70	1964.70	2687.51	722.81
2015	0	54.00	1080.00	1100.70	2180.70	3378.58	1197.88
2016	0	54.00	1134.00	1270.80	2404.80	4181.00	1776.20
2017	0	66.00	1200.00	1450.80	2650.80	5110.11	2459.31

As per above analysis the expenditure can be paid back along with compound interest (@ 15%) in 6 years (2012). Thus, in remaining 4 years (out of ten years O&M period) plant will generate power amounting to approx. 24.59 crores (in terms of money); which can be utilized for other works. There will be a generation of 3.46 crore power units (KWH) during 10 years period; this power can be gainfully utilized for some other work.

RE-USE OF TREATED WATER (SECONDARY TREATED EFFLUENT)

One of the most critical steps in any reuse program is to protect the public health, especially that of workers and consumers. To this end, it is most important to neutralize or eliminate any infectious agents or pathogenic organisms that may be present in the wastewater. For some reuse applications, such as irrigation of non-food crop plants, secondary treatment may be acceptable.

For other applications, further disinfection, by such methods as chlorination or ozonation, may be necessary.

Some guidelines for the utilization of wastewater, indicating the type of treatment required, resultant water quality specifications, and appropriate setback distances are available in USEPA (1992). In general, wastewater reuse is a technology that has had limited use, primarily in small-scale projects in the region, owing to concerns about potential public health hazards. Wastewater reuse is primarily in the form of agriculture, forestation, groundwater recharge or pasture development without further treatment. This would further result in savings of power as pumping of groundwater from deep strata will be reduced. Guide lines for such reuse given in Table 7.

Table 7: Guidelines for reuse options for treated wastewater (USEPA, 1992)

Type of Reuse	Treatment Required	Reclaimed Water Quality	Recommended Monitoring	Setback Distances
AGRICULTURAL Food crops commercially processed; Orchards and Vineyards	Secondary Disinfection	pH=6-9	pH weekly	300 ft from potable water supply wells
		BOD = up to 30 mg/l	BOD weekly	
		SS = up to 30 mg/l	SS daily	
		FC = up to 200/100 ml	FC daily	100 ft from areas accessible to public
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	
PASTURAGE pasture for milking animals; pasture for livestock	Secondary Disinfection	pH = 6-9	pH weekly	300 ft from potable water supply wells
		BOD up to 30 mg/l	BOD weekly	
		SS up to 30 mg/l	SS daily	
		FC up to 200/100 ml	FC daily	100 ft from areas accessible to public
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	
FORESTATION	Secondary Disinfection	pH = 6-9	pH weekly	300 ft from potable water supply wells
		BOD up to 30 mg/l	BOD weekly	
		SS up to 30 mg/l	SS daily	
		FC up to 200/100 ml	FC daily	100 ft from areas accessible to the public
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	
AGRICULTURAL Food crops not commercially processed	Secondary Filtration Disinfection	pH = 6-9	pH weekly	50 ft from potable water supply wells
		BOD up to 30 mg/l	BOD weekly	
		Turbidity up to 1 NTU	Turbidity daily	
		FC = 0/100 ml	FC daily	
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	

The parameters of the treated sewage shown in Table 5 indicate that this effluent can be used for agriculture for raising certain types of crops, forestation and pasture development without any further polish. Thus it can result in substantial saving of energy that otherwise would have been consumed for pumping equivalent quantity of water from underground sources. Assuming an average depth of water table in the area to be about 80 metres, the energy saving would amount to about 575 KWh on a daily basis.

CONCLUSIONS

The biogas produced at STP Delawas contains 52-57% of methane which can be used to generate electricity of 475 KWh/ day. About 60% of the plant 's energy expenditure can be met through this power generation using digester gases. The power generation plant would require capital and operating costs of about 750 lac and 2.5-3.00 lacs/ month respectively. The electricity produced would be able to recover these costs in a period of about 5 years. The provision of VFD has brought down the operating cost of the plant substantially and inclusion of indirect benefits like reduction in the pumping costs can justify all such measures taken in STPs to reduce the energy requirements.

ACKNOWLEDGEMENTS

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Cost Savings through Energy Audit and NRW Study of Water Supply Schemes in Rajasthan- A Case Study

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ABSTRACT

Urban Water Supply Management consumes around 60-70% of total O & M expenses in power consumption. In addition, about 15-25% quantity of water goes waste as un-accounted water in water supply system. Conservation of both WATER and ENERGY if attempted together in any Urban Water Supply system would yield sizeable value to the theme of conservation. There is always gap in expenditure & revenue. This gap can be reduced either by decreasing O&M expenditure and or by increasing tariff. The first effort should be to decrease O&M expenditures because public should not bear penalty due to inefficiency of the system. RUIDP has conducted energy audit & NRW Study in six towns namely Ajmer, Jaipur, Kota, Udaipur, Udaipur & Bikaner. Jodhpur water supply was reorganized in totality & raw water conveyance system of Udaipur was redesigned. in Jodhpur **23380 KWH / day (Rs. 1.40 lacs power charges per day)** has been saved by getting topography advantage & in Udaipur by avoiding raw water pumping **23378 KWH / day** (Rs. 1.39 lacs per day) has been saved. After Energy audit & NRW study conducted in six towns, 36530 unit/day **(2.19 lacs** per day) power charges have been saved by replacing inefficient pumping machinery& by replacing of leaking lines in Kota & Ajmer have reduced NRW from **40-45% to 25-30%**. Thus total the power saving per year is Rs. 1824 lacs. The present paper describes the details of the energy audit and NRW studies and the corresponding savings in power consumption in the six towns of Rajasthan.

INTRODUCTION

The Govt. of Rajasthan has formed RUIDP and entrusted the works of the infrastructure development in the six cities to RUIDP. The loan of Rs. 1500 crores for phase-I was from ADB to government of India for providing infrastructure facility in six divisional headquarters cities – Ajmer, Bikaner, Jaipur, Jodhpur, Udaipur, and Kota. The sectors wherein Works has been executed under RUIDP in phase-I are:-

- Water supply rehabilitation and expansion& Urban Environmental Improvements.
- Wastewater Management, Solid Waste Management, Drainage and Slum Improvements.
- Urban Transportation Management
- Fire Fighting Services, Development of Sites and Services including Historical Sites
- Community Awareness and Participation Program & Capacity Building and computerization of urban local bodies.

The population of six project cities is 52.93 lakhs as per the 2001 census which is now about 70 lacs. Investment made in project cities which save the power charges in by reorganizing & under NRW works is tabulated in table no.1 below:-

Table -1 City wise investment made on WS & Inst. of flow meters

S. No.	City	*Expenditure (Rs. In Lacs)		
		Water supply sector	Installation Bulk flow meter under NRW reduction	Total
1	Ajmer	1721.83	65.00	1786.83
2	Bikaner	51967.1	35.00	52002.14
3	**Jaipur	52646.7	110.00	52756.71
4	Jodhpur	1564.64	38.00	1602.64
5	Kota	5364.3	25.00	5389.30
6	Udaipur	4004.65	20.00	4024.65
Total		117269	293.00	117562.27

* some packages final bill yet not finalized, ** includes Jaipur Bisalpur Project

The work executed by RUIDP in Water supply sector with some innovative ideas such as to get the advantage of natural topography in re-organization of main water supply lines especially at Jodhpur, Udaipur, Replacement of inefficient pumping sets, conducted Energy audit first time in State.

REVENUE & EXPENDITURE

There is vide gap in expenditure and revenue for water supply systems as evident from the table-2 given below:-

Table 2 Citywise scenerio of revenue gap

Name of Town	Revenue in Rs. Crore per annum	Direct O&M Expenditure (Rs. in Crore) year		
		Power Charges	Other maintenance expenditure	Total
Ajmer	5.61	28.67	7.71	36.38
Bikaner	5.92	9.73	9.48	19.21
Jaipur	21.00	27.00	23.02	50.02
Jodhpur	14.14	42.79	16.70	59.49
Kota	8.98	11.43	9.82	21.25
Udaipur	3.73	14.76	6.83	21.59
Total	59.38	134.38	73.56	207.94

Source- data year 2004-07- RUIDP/PHED

As the matter of fact the revenue should be sufficient to recover the direct O&M expenditure and the interest on investments made and depreciation of assets. Thus at present we are far behind the objective. The gap in expenditure & revenue can be reduced by decreasing O&M expenditure and by increasing tariff. The first effort should be to decrease O&M expenditures because public should not bear penalty due to inefficiency of the system. The major part of O&M expenditure in water supply schemes is due to power as evident from the table given above. The revenue from water supply system does not even cover 50% of the expenditure on power alone.

CASE STUDY

RUIDP with some innovative ideas re-organized the Water supply system of Jodhpur & Udaipur. In both the reorganization Schemes importance was given to save pumping (to save energy) & use natural topography advantage of the area. Jodhpur & Udaipur city are two examples of re-organizing water supply schemes with getting advantage of natural topography.

1. JODHPUR

Jodhpur urban water supply system came into existence in the year 1886 & has been augmented many times since then. This raw water from RGLC is stored in two impounding reservoirs namely Kayalana & Takhat Sagar. Three major water supply zones exist is the town, which are based on water treatment plants (WTP) at Kayalana, Chopasani & Jhalamand locations. The WTP at Kailana supplies water to Central Walled city, northern and eastern part of the city. The Chopasni supplies mainly to western and a part of southern city. Jhalamand WTP supplies water to part of southern and eastern side of the city. Under the recently executed Rajasthan Urban Infrastructure Development Project (ADB funded) the major water transmission system has been optimized to impart the benefit to the serving areas with least power consumption. For this the topography advantage provided by the founders of Jodhpur city was well studied. This transmission system comprising of 1000 mm dia- meter to 200mm diameter (telescopic sizes) DI pipe line is supplying uninterrupted treated water to 20 no. service reservoirs, out of which 10 no. are receiving water absolutely with gravitational head & for other 10 no. reservoirs, booster pumps have been installed. As a result, it has saved mega watts of energy consumption. Total length of this transmission system laid & commissioned is about 20 Km. A comparative study of serving areas before & after execution of RUIDP work is shown in the table-3 below:-

Table-3- Status of before 7 after execution

S.No.	WTP Zone	Before re-organization by RUIDP	After re- organization of Water supply by RUIDP
1.	Kaylana	60 MLD By Pumping only: Central walled city, Northern & Eastern part of the city	80 MLD by Gravity & 38 MLD by pumping.
2.	Chopasni	56 MLD existing system	50 MLD existing system. No change
3.	Jhalamand	51 MLD existing system	51 MLD existing system 5-6 MLD by gravity from Kailana.

The total population as per 2001 census is 8.51 lacs & present population is about 10.0 lacs. The present supply is about 220 MLD including bulk demand of 55 MLD to army, industries etc. Present actual rate of supply is about 140-160 lpcd. Salient Features of Kaylana gravity system laid by RUIDP is as per table-4 & system energy consumption detail is at table-5.

Table-4- Salient Features of kailana gravity system

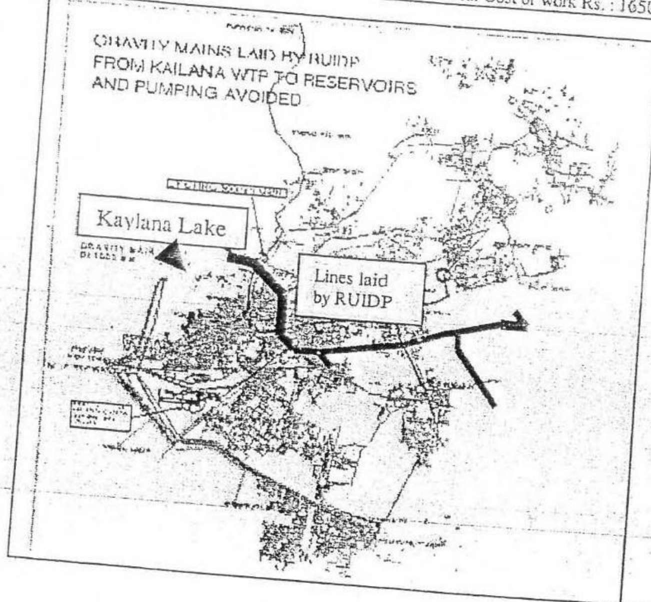
Design year	2034			Design Flow	Yr.2011 66.05 MLD		Yr.2034 102.98 MLD			Service Reservoir connected- 20 nos.		
Diameter(mm)	1000	900	800	750	700	500	450	400	350	300	250	200
Length(m)	4822	1880	30	1333	2103	37	2178	2457	1598	827	2153	570
Served Population		Yr. 2011 4.00 lacs		Yr. 2034 5.00 lacs								

On Line Boosters: Additional pumping to following service reservoirs required to meet the head requirement at their inlet.

Boosting Location	Name of ESR/GSR	Required duty condition of Booster Pumps		
		Discharge (m3/hr)	Head (M.)	Configuration
Kabeer Nagar PS (+ve suction head utilized)	Kabeer Nagar	140	30	1+1
	Bheel Basti	21	35	1+1
Masuria PS	Suraj Bera/Soorsagar	313	57	1+1
	Bhika Piao Pratap Nagar Jagdamba Colony	275	57	2+1
Ummed Hospital PS (+ve suction head utilized)	Ummed Hospital	100	10	1+1
Baiji Talab PS (+ve suction head utilized)	Baiji Talab	350	9	1+1
Girdhar Mandir PS (utilises +ve suction head)	Girdhar Mandir	152	22	1+1

Execution Period: 23 Sept. 2002 to 31 Dec. 2004. Total Cost of work Rs. : 1650 Lacs

source-RUIDP/PHED Jodhpur



DI pipeline of 1000 mm from Kailana to Paota is running under gravity without any pumping and 7 No. reservoirs are being fed by gravity. With this innovative design large part of Jodhpur is getting water without pumping from Kaylana where as same area was getting water previously with pumping.

Source- RUIDP Jodhpur/ PHED Jodhpur

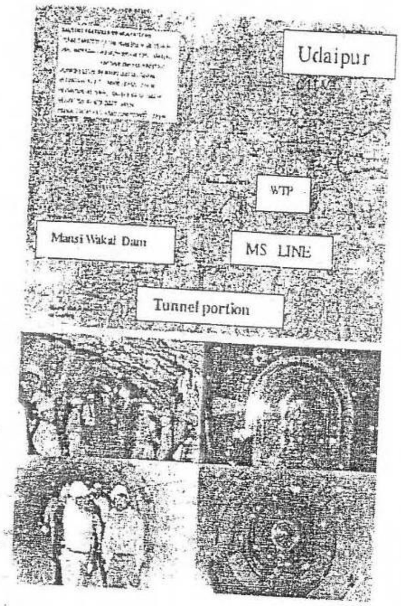
Table-5 Energy consumption and saving

S.No.	Description	Annual Cost (Rs. In lacs)
1	Total Cost of energy for Existing system of 140 Mld (Unit Cost Rs 2.12 per Kl – Based on the pump KWH for the existing water supply system and unit energy rate)	1083.02
2	Total Cost of energy for Existing system with proposed Re-organization of the system (Unit Cost Rs 1.83 per Kl) Based on the pump KWH for the re-organized water supply system and unit energy rate)	940.21
3	Saving in Energy Costs for existing works	142.81
4	Additional energy cost for Proposed system for pumping of additional 60 Mld flow (115 KW x 22 x 365 x 4.75 x 2)	87.73
5	Cost of energy for proposed augmentation of 60 Mld (87.73 x 100,000/-) / (365 x 60 x 1000)	0.4/Kl
6	Total energy cost for the proposed system of 200 Mld (Cost of existing system with re-organization + Cost of new system) (Rs 940.21 + Rs 87.73)	1027.94
7	Unit Energy Cost for the Combined system (1027.94 x 100000) / (365 x 200 x 1000)	1.41/Kl
8	Realistic saving in Energy cost Sr no 3 + Sr No 8)	222.81
9	Energy savings with the assumption that with faulty design the water production cost would have remained same as Rs 2.12 per Kl for the combined system also. (2.12 – 1.41) x 200 x 1000 x 365 / 100000	518.30
10	Overall saving in energy cost including refurbishment of pumps	598.30

Note: - The unit energy cost for the existing system and proposed system is calculated on the basis of KWH of pumps, water supply, hours of pumping and power rate.

2. UDAIPUR

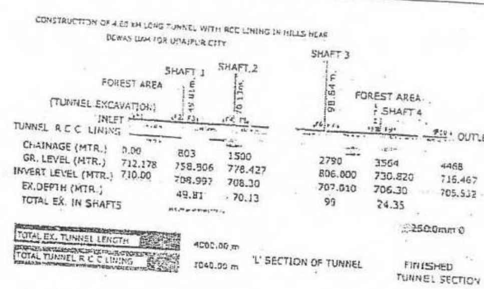
Government of Rajasthan and Hindustan Zinc Limited (HZL) has jointly implemented a prestigious water supply project for Udaipur city called Mansi Wakal Project which involves construction of Dam and carrying water from Mansi Wakal Dam to Udaipur. As per the agreement with Hindustan Zinc Ltd., the Construction of Dam, Pump Houses and Pipeline from Mansi Wakal to Dewas has been executed by HZL and work of Construction of Mansi Wakal Dam, Pumping Station and 800mm dia. MS pipeline 8.10 km. long from dam to Tunnel Inlet has been executed by Hindustan Zinc Ltd. and Pipeline was to be executed by PHED. Later on PHED's part for pipeline was included under RUIDP's scope. RUIDP after various alternatives designed a system which involved a construction of 4.80Km. tunnel to reduced/avoid the pumping which was earlier to be constructed by PHED. By this innovative approach the pumping of 110 mtr has been saved to pump the designed flow of 36.15 MLD. The work of 4.60 km. long tunnel, 7.6 km. long 800 mm dia. MS pipeline from tunnel outlet to treatment plant at Nandeshwar, Construction of 23.35 MLD capacity water treatment plant at Nandeshwar and gravity mains from Nandeshwar Treatment plant to various service reservoirs of Udaipur has been executed by RUIDP. The cost of above works was Rs. 3323.07 lacs. Salient features of Tunnel are at table-6



Photographs during execution curtsy by RUIDP)

Table-6- Salient features of Tunnel

Salient Features of Work executed by RUIDP	
Designed capacity of pipe line	36.15 MLD
Pipe Material	MS with Inside CML coating 7 out side enamel coating
Pumping Level at Mansi Wakal	562 mtr.
Level at Tunnel Base	744 mtr.
Level at Tunnel out let Base	742 mtr.
Level at WTP Inlet	693 mtr.
Level at existing road junction	720 mtr.
Length of Tunnel	4.00 Km.
Size of finished tunnel	2500 mm



L- Section of Tunnel

1. Energy Audit conducted by RUIDP

To reduce the expenditure on power, there was urgent need to under take energy audit. Efficiency of 298 pumping sets in 6 project towns was measured. Such audit was done for the first time; it was found that the pumps are operating at very low efficiencies resulting thereby in high consumption of electricity. Based on the study, RUIDP has prepared design reports to replace 159 pumping sets in 6 towns at cost of Rs. 922 lacs. New configurations of pumps were proposed with maximum attainable efficiency so that by changing pumps the saving in energy charges becomes to Rs. 1045.88 lacs per annum. The energy saving & cost of replacement cost of pumps is tabulated below:-

Table-7- Energy saving & pumps replacement cost- Cost in Rs Lacs.

Name of —	Pumping sets tested	Efficiency	Age of Pumps (in Yrs.)	Proposed efficiency (in %)	Cost of replacement		Energy)
					No.	Cost in lacs	
Ajmer	26	14-50	20	65-72	10	41	100
Jaipur	123	20-70	25	75-90	64	300	200
Jodhpur	52	23-70	20	70-80	34	140	130
Kota	45	40-55	5-20	70-80	15	85	135
Udaipur	52	35-60	30	70-75	21	441	380.88
Bikaner	32	40-56	5-20	70-85	15	85	100
Total	298				159	1092	1045.88

While proposing replacement of pumps, not only low efficiency parameter was considered but age of pump was also given due weightage. Weightage was also given to period in which the expenditure of replacement is recoverable by saving energy charges. old pumps require frequently repaired and their operational costs were very high. Weightage was also given to efficient system to the extent of capitalized cost of difference in energy consumption cost for 10 years at 10% discounting. Thus energy efficient systems with less energy consumption were selected.

2. **City wise work executed as per energy audit (from 2003-2005)**

(a) **UDAIPUR CITY**

For Udaipur water supply the head of pumps at Jaisamand PS I, PS2, PS3 & PS4 were 145 m but operating heads was much less. Accordingly the pumps were not operating at duty point peak efficiencies. The efficiency of these pumps was measured and was found to be 42% to 59%. Now, pumps of 515 m3/hr having efficiency 70.4% and operating heads for different pumps (97 m to 125 m) as per design demand has been installed. At Dood Talai PS1 & PS2 there was high negative suction head of 6 m and efficiency has gone down by about 20%. On these Pumping Stations it was proposed to lower down the platform to reduce suction head and to replace the old pumps with energy efficient pumps. At Fateh Sagar Dewali pumping station the existing pumps were running at low efficiency and low head and therefore these are to be replaced. At Jhamar Kotra pumping station, pumps were running at high discharge but the head developed was very less than the rated head and therefore these were replaced. Expenditure incurred on replacement of pumps & annual power saving is tabulated below.

Table-8- Expenditure and saving on replacement of pumps at udaipur

Name of P.S.	Total expenditure on replacement of pumps	Savings/ annum(Rs. In lacs)
Jaisamand PS1	106.48	76.60
Jaisamand PS2	65.86	84.91
Jaisamand PS3	61.36	59.26
Jaisamand PS4	65.86	47.33
Doodh Talai	72.38	31.00
Fateh Sagar	45.61	45.87
Jhamar Kotra	9.21	24.91
Gulab Bagh	15.10	11.00
Total	**441.86**	**380.88**

(b) BIKANER

Earlier water supply to Bikaner town was 68 MLD out of which 33 MLD was from Beechwal Water treatment plant. Water from Beechwal after treatment was pumped to intermediate pumping station and from there it was pumped to Stadium ground level tank. The pumps installed at Beechwal were of 41 m head which were not match with the actual head and thus not operating at duty point peak efficiency. After laying new line the required pump head is 23 m against previous head of 41 m. Thus there is Energy saving by replacing pumps. The cost of replacement of pumps at Beechwal was Rs 150 lacs. This expenditure incurred has already been recovered by saving energy charges. Flow is under gravity in new system from IPS to stadium. The expenditure of pipe line from Beechwal to IPS and from IPS to stadium was Rs. 4.63 crores and water is being fed directly in service reservoirs under gravity.

(c) KOTA

At Kota in World Bank pump house at Akelgarh , the existing pumps consume more energy because of their NPHSR were not matching with requirements NPHSR. This was observed during measurement study carried out by RUIOP. The observed flow rate was only 52% of the design flow rate. The drop of 48% discharge of the pump was highly undesirable and it necessitates the replacement of pump on top most priority. Now proper head discharge efficient pumps have been installed in a cost of Rs. only 12.45 lacs. Earlier because of less discharge of the pumps the water treatment plant at Kota was getting 92 MLD water against capacity of 128 MLD. Thus by installing these pumps water supply to Kota has increased by 36 MLD. The installation cost has already been recovered in 6 months only.

(d) JAIPUR

There were 52 functional pumping stations in the city with 119 pumping sets. Out of these 64 pump sets in 31 pump sets were replaced and handed over to PHED. Due to less efficiency of these pump sets, excess of power consumption and less water discharge was problem. These works have resulted not only more availability of water but has reduced power consumption by Rs. 1.00 crores annually. The cost incurred was Rs. 2.33 crores which has already been recovered through energy saving.

(e) JODHPUR

52 pumping sets were tested at various pumping stations in the city. Out of these, 35 pump sets were replaced and handed over to PHED. Due to less efficiency of these pump sets, excess of power consumption was there and less water discharge was also getting. These works were resulted not only more availability of water but has also reduced power consumption by Rs. 1.30 crores annually.

(f) AJMER

26 pumping sets were tested at various pumping stations in the city. Out of these, 10 pump sets were replaced and handed over to PHED. Due to less efficiency of these pump sets, there was problem of excess power consumption. Now after replacement power consumption has reduced 7 less power city is getting more water. There is saving of Rs. 1.00 crores annually on power account.

3. NRW Study results/ recommendations & works executed

KOTA

The first slow sand filter plant of 4.5 MLD capacity was constructed in 1934-35. This is presently abandoned. Since then four more plants were added. The clarifloculators have heavy leakage and considerable seepage was observed from the filters of the 7 MLD Patterson plant constructed in 1961 and 18 MLD Geomiller- plant was constructed in year 1974. The estimated physical loss was more than 15% of the rated capacity. These Plants were abandoned due to above leakages. The expansion joint of raw water inlet channel 128 MLD plant was leaking heavy and was repaired. The losses in Mahaveer Nagar feeder main observed very high and it was one of the most problematic pipe line reported by PHED This pipeline was a classic case of poor workmanship and wrong selection of pipe material (AC pipe laid in rocky strata). This main line was operated much below the rated pressure to minimize the leakage. Congested walled city area has maximum leakage as distribution main system was laid in the year 1927-28.Eight pipe lines at various places in the city were identified as having more leakages. There was about 84.8 lacs liter water per day from 53 lacs liter capacity CWR at Akelgarh. There was about 18.70 lacs liter water per day from 23 lacs liter capacity CWR at Akelgarh. Mahaveer Nagar ESR has abnormally heavy leakages and as such not used. Out of total storage of 400 lacs litres at Akelgarh only storage of 54 lac liters was in intact position and other tanks were badly leaking. Consumption of water varies from 158 LPCD to 117 LPCD. Water lost at Akelgarh head works alone was observed 38 MLD due to heavy leakages in structures. This was 15% of supply to Kota. RUIIDP completed the most of above works including repairing of Mahaveer Nagar OHSR which is now in use. The main trunk lines of DI pipes from Akelgarh Head works to various places in the city have been laid. One WTP of 64 MLD along with 106 litre capacity CWR at Akelgarh has been constructed & commissioned. The total expenditure on these works is about Rs. 40.00 crores. Without increasing production about 15-20% supply has been increased. This has saved energy which was to be consumed for pumping of 18-23% raw water demand from river.

JAIPUR-

PHED conducted NRW study for Jaipur city for reduction in non revenue water through French consultant SURECA. Pilot area studies were conducted for determination of unaccounted for water (UFW) in Mansarovar Sector 9 & 10, Gangapole, Civil Lines, Gandhi Nagar, AG Colony, VKI area, Baees Godown and Brahampuri. The work included setting and verification of district metering area (OMA) consisting of about 9000 consumer connections. flow monitoring, leak detection and repairs, final Monitoring, leakage at target pressure and analysis and reporting. Study revealed that:-

- 60% of the non functional water meters were charged on estimated bill basis and such charges were being over billed for domestic and industrial consumers but commercial consumers were being charged under bill. On an average basis the non functional water meter consumers were over billed by 20.5%.The result of 1427 no. meter were tested for accuracy in workshop & observed that average error for nominal flow was -14.2%, for transitional flow was -24% and for minimum flow it was-42.8%. The sample serial meter study conducted in pilot area indicated that in the cases of consumer meter both under and over reading has occurred, with overall error being an over reading of 0.6%. The average consumption per property per day was ranges from 514 liters (103 LPCD) for domestic to 1228 liters for industrial. The number of non-functional consumer meter were extremely high .The repair of existing leakages were negligible

- Overall level of UFW was 44.2%. UFW was high in north zone 47.3% as compared to South zone 9.10%.UFW at water treatment plant was 16%. UFW in raw water mains was ranging from 4.3% to 32.4% maximum (in 600 mm AC main line). UFW in tanks was about 4.2%. The percentage of consumer's meter complying with class 0 accuracy standard was as low as 21 % .The meter testing and repair workshop did not comply with the relevant Indian Standards (IS 6784).For PSP's located in housing area the wastage was 17% and for PSP's located in commercial area the wastage was about 50%

Important recommendations:-

- Reporting and repair of visible leaks. Installation of permanent bulk meters at all distribution centers. Preparation of maintenance manual. Identification of preferred type and manufacture of consumer meters. Identification, categorization and prioritization of all valves in the system. Monitoring of flows and pressures at all distribution centers .Replacement of all consumer meters. Responsibility for all consumer meters and service connection to be of PHED. Commence routine and preventive maintenance. Implementation of valve maintenance. Implementation and monitoring of District Meter Zones. Replacement of all service connections.

AJMER

- The pipeline from SR 7 to Alwar gate consists of 30" MS pipe line was laid in the year 1965. This line was corroded; especially which is laid underground and thickness has reduced to 2-3 mm from original 6 mm. This pipe line has history of chronic break down and intense leakages paralyzing tile supply of the city. For fear of burst the line is not utilized to full capacity. CI lead jointed pipe line from Nursing home to PS 8 and pipe line from PS 8 to Babugarh SR (30 year old lead jointed with MS portion) were frequently leaks. Wastage / misuse in Dargah area is 3 to 4 times the requirement. Babugarh Reservoir, old Reservoir at SR 7, industrial area over head tank, PS 3 & PS 5 reservoirs were substantial leaking. Pipe line between Goyala to Nasirabad bursts frequently and repair time is 48 hrs and supply gets affected as storage at SR 7 is of 2 hours only. The quantity of water billed on average basis was on higher side than the actual.

3. Assessment of NRW:

The NRW study done by RUIDP indicates cost of water lost at Kota is Rs. 16.87 crores & at Ajmer is Rs.2.9 crores per year. Details of water loses Ajmer & Kota are tabulated in table 9.

Table-9 Water lose in Kota &Ajmer

Name of town		Ajmer	Kota
Production in MLD		74	207
Water Billing (MLD)	Based on meter	10	32
	Based on average	38	37
NRW	MLD	26	138
Water connections		60000	85000
Water used per connection in lit.		740	684
Water losses per connection (liters)		401	1368
Water losses in terms of per person (liters) considering 6 person /connection		66.83	273.6
% Losses (NRW based on functional meters only)		35	150
Sold Average cost of water in Rs/KL		3.1	3.35
Annual cost of water lost(in crores)		2.9	16.87

4. **Working methods followed by RUIDP**

As per NRW study RUIDP executed works considering following issues-

a. **Improved pipe laying methods**

As recommended in NRW study, RUIDP has followed best practices in laying pipe line for their project works such as,

- Earth cover of 1 m minimum on pipe line make essential.
- Field testing at 1.5 times design pressure/permissible pressure was done for all lines laid and payment is done only after field testing. Only standard fittings specials to be used in pipe lines. Minimum bends in horizontal and vertical direction while laying pipe line.
- EPDM rings which are ant termite introduced for joining of pipes. Thrust blocks at all bends, tees, dead ends to be provided. Good quality pipe has been proposed. PVC pipe with rubber rings was used.
- AC pipe class- 15 was used in soft soils and DI pipes e used for important transmission mains and in rocky strata.

b. **Marking of pipe lines / location of OHSR's on NRSA map**

RUIDP has marked existing pipe lines up to some extent as per data provided by PHED, new lines laid by RUIDP and service lines on NRSA maps of all 6 project towns and provided to line agency. These maps will help in O&M & further reorganization of Schemes.

c. **Development of system with less NRW**

In Jaipur RUIDP has covered some new areas developed by cooperative societies. Since these are total new water supply systems, RUIDP has developed them as model systems with 24 hour supply which would be possible with present LPCD and restricting NRW to 15%. Bulk meters on tube wells, bulk meter on reservoirs has also been installed to measure the production & supply. The total city area has not been covered by RUIDP looking to the availability of funds. It is also suggested that all consumers should have domestic water meters of good quality so that NRW can be assessed and controlled. It was also proposed to have only MDPE service lines and ferule connection with good quality and through contract under RUIDP/PHED and not by plumber.

d. **Replacement of leaking pipe lines**

RUIDP has not completely replaced the leaking pipe lines, polluting pipe lines and other pipe lines to reduce NRW due to restricted availability of funds and time bound project period. In Jaipur PHED has taken up such work on priority now.

e. **Replacement of Domestic Water Meters**

If all non functional water meters replaced and provide meters on flat rate connection then the cost of providing good quality water meters with 7 years maintenance would cost about Rs. at Rs. 1000/- per meter. This is huge investment and has to be properly evaluated versus benefits. NRW report also reveals that at present connections with non-functional water meters are charged on average basis which is being done arbitrarily and is on higher side (about 20%) then would have been on basis of actual consumption. Thus metering may reduce revenue. Although it will reduce consumption and introduce correct charging instead of present wrong and higher charging. However benefit of reduction in consumption by way of full metering would be available only when tariff is increased as with present low tariff rates there is no incentive to reduce consumption.

The other purpose of full metering is to assess NRW and introduce active leakage control programme on performance target based NRW reduction. However this requires bulk metering on large scale and separation of zones. Perhaps at present we are not able to invest for large scale metering bifurcation of each zone from adjoining zones.

f. **Replacement of Service Lines**

Service lines are generally provided of GI pipe which has tendency of corrosion and therefore has life of only 25-30 years. Therefore, service lines particularly in city portion, where water connections are existing since more then 50 years need replacement. Many consumers, where long service lines required, lay alkathene pipe lines to save on cost. These pipes are of extremely poor quality and leaks excessively. Many service lines have been laid on road without proper cover and therefore frequently leaks. Some service lines pass through road drains and sometimes enter the house wall through house drain. Such service lines corrode soon and some holes develop through which drain water sucks and water quality is deteriorated. PHED has recently decided to allow use of only MDPE pipe for service lines. This should be strictly implemented. Also it should be ensured that service line does not pass through drains and should always be laid with at least 60 cm cover. Also on roads and drains sleeve pipe should be provided on service lines.RUIDP planned to prepare package for replacement of service lines of all consumers in walled city portion where NRW levels are abnormally high. However, service line replacement is responsibility of consumer. The work was executed by RUIDP. PHED should take this work on top priority.

g. Providing Bulk water meter

The purpose of providing bulk meter was as follows:

Generally the quantity estimated on the basis of running hours of pump multiplied by their design discharge. This does not give correct picture as the actual discharge of pump differs widely from design discharge. Actual supply of town can be assessed correctly by installing bulk flow meters. In case of Jaipur water supply is from tube wells. Some times the pump discharge goes down due to various reasons and pump becomes inefficient; However, in absence of bulk meter low discharge could not be generally detected. Thus pump continues to run & gave less discharge and consuming more energy without being detected. This not only decreases the production but results in more energy consumption. Bulk meter can detect such situation and rectification of remedy can be take up which will improve system efficiency. Many time water is transferred from one zone to other zone particularly from zone with more water to deficit zone. The transfer of required quantity is monitored by number of hours the pump runs. Some times wrong and manipulated information are given and as such correct monitoring becomes difficult and deficit zones suffer more. Bulk metering on transfer mains can solve this problem. Leakage level at strategic points such as on important transmission mains and treatment plants can be known correctly if bulk meter is installed at beginning (starting point) and at end (receiving point).Tube wells aloe generally required to run 24 hours. However due to shortage of staff one man is responsible to run 20-30 tube wells. This results in closure of tube wells and reduction in production. Effective monitoring to ensure all tube wells running 24 hours is not possible. Also submersible pumps are replaced about once a year. The new pump may not be giving full discharge. Also discharge may reduce due to leakage inside tube well or any other reason. By putting bulk meters such things can be detected and rectification will increase production and result in less electric consumption per unit water produced.By bulk metering each zone and bifurcating one zone from other zone and ensuring functional domestic water meters on all consumers the NRW can be assessed correctly and corrective measures can be taken to reduce NRW. However for efficient corrective measures even one distribution zone needs to be bifurcated in 3-4 sub zones called District Meter Areas (DMA). Bulk meters should be installed to measure inflow in each DMA and every DMA should be bifurcated from other DMA. This system requires number of bulk water meters and number of sluice valves. Perhaps at this stage investment to this extent is not feasible. Therefore development of one or two DMA's in each city in first instance may be taken up. NRW consultant engaged by RUIDP has done detailed assessment of various types of bulk meters manufactured and their relative merits and demerits and has recommended Electromagnetic type bulk meter and specifications for procurement. Work for supply, erection and maintenance (for 5 years) has been done as detailed in table-10:

Table-10 Bulk flow meter installed by ruidp in six project towns under nrw project

Size up to 300 mm								
s. no.	Size of Flow meter (mm)	City						
		Jaipur	Jodhpur	Bikaner	Kota	Udaipur	Ajmer	Total
1. 1	150	1	1	11	1	4	-	18
2. 2	200	35	-	8	-	1	2	46
3. 3	250	11	4	2	2	-	-	19
4. 4	300	09	1	5	-	2	2	20
5.	350	2	1	2	-	1	-	06
6.	400	3	2	6	2	2	5	20
7.	450	1	-	-	-	-	-	1
8.	500	-	3	2	4	-	2	11
9.	600	1	1	-	1	-	1	4
	Total	63	13	36	10	10	12	145

Total expenditure on installation of Bulk Water Meter in above six cities & their maintenance for 5 years is Rs. 306.00 lacs.

CONCLUSIONS

The present case study clearly depicts that sizeable saving is possible in electricity consumption to produce water in urban water supply systems, if attempted with a sound & good Engineering practices in re-organizing the Water supply is truly adopted. RUIDP has initiated that how the natural topography can be used & how energy can be saved. how water supply system can also made sustainable. How O&M cost can be reduced. If production cost of water is reasonable then there is no need to go for any sudden increase in water tariff. The Energy audit is a very use full tool by which energy & water can be saved for future. Energy audit can be done for buildings, Water & Wastewater Treatment Plants, by such audits Government can save lot of money which is going waste & can save mega watts of Energy. Non Revenue Water (NRW) is a major problem in Urban & rural Water supply projects all over the country. There is need to implement the findings of NRW study conducted by RUIDP in totality in all six project towns so the water & energy losses may be reduced. It may be also helpful in reducing water pollution up to the some extent. RUIDP has made study in Udaipur, Ajmer Jaipur, Jodhpur, Kota & Bikaner. The work has not been done in totality as per findings of the NRW study. Concerned Agency should take those remaining work on top priority & reduce NRW. This will save energy & water for future. India's Urban Water Supply sector is facing acute problems, as the water supply organizations are not financially sound. The existing services are falling short of full coverage of population and are often of low quality mainly due to insufficient funding of O & M. Thus there is an urgent need to check reliability of the existing urban water supply schemes. If we can reorganize/ augment the schemes by reduced net power input through alternative proposals that should be encouraged. Every body from us can very well realize the losses taking place from WIRE TO WATER i.e. transformer losses, electric installation losses (less power factor etc.), cabling losses, variable speed drive losses. motor & pump losses due to improper duty conditions/ reduced efficiency, transmission system losses etc. Improvement in any or all of these sectors can lead to power saving. Money saved by minimizing operating expenditure e.g. in power etc., can be utilized for up-gradation of the system.

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Waste to Energy –Power generation at 62.50 MLD (unit-I) Sewage Treatment Plant Delawas, Jaipur- Rajasthan-India- A case study

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ABSTRACT

Power consumption accounts for almost 75% of the expenditure on O&M of any sewage treatment plant working on aerobic biological process. STP Delawas, Jaipur based on conventional activated sludge process was commissioned by RUIDP in 2006 with a capacity of 62.5 MLD. The average daily power consumption for operation of STP was 8576 Kwh, which amounted to an electricity bill of more than Rs 12.0 lac per month prior to the installation of power generation unit based on biogas fuel. Apart from power generation, energy saving measures taken for the plant operations have resulted in substantial saving in the energy costs. Variable Frequency Drive (VFD) has been provided for the first time in Rajasthan in a STP. Man Machine Interface (MMI) is provided through Programmable Logic Control System (PLC) for handling anaerobic sludge digesters that produce about 5800-6500 Nm^3 of gas per day, which is being utilized for power generation. An analysis of five year data shows that the maximum power generated was about 270115 kWh/month in March, 2010 (Av. 8713 KWh/day) and lowest 41694 kWh/month in February, 2011(1490 KWh per day) through gas engine. This has made the STP almost self sufficient (except for meeting peak hour demand) in terms of power requirements.

INTRODUCTION

Sewage treatment is a significant user of energy. Operation of pumps, blowers and other equipment at a typical sewage treatment plant (ASP /extended aeration) per person an annual electrical energy consumption requirement is in the range of 12-19 KWh (Arceivala & Asolekar, 2006). Thus, substantial input of energy is required to treat sewage from densely populated areas, and sewage treatment often comprises the largest use of electricity by local governments. Conventional STPs remove organic content from the water stream by reacting the proteins, fats and carbohydrates with oxygen from the air. This oxidation process is undertaken at ambient temperature by the enzymes secreted by aerobic bacteria and converts most of the organic material to carbon dioxide and water through dissimilatory process. The process also produces sewage sludge, or bio-solids, consisting of un-oxidized organic matter and predominantly bacterial cells. Some treatment plants further reduce the quantity of bio-solids through an anaerobic treatment process. Here, in the absence of air, anaerobic bacteria digest the bio-solids, producing "biogas", a mixture of methane and carbon dioxide. Methane is the main component of natural gas, and the biogas produced, can be burnt in an engine or turbine to produce power and generate electricity. In this way, anaerobic treatment can generate electrical energy used in the sewage treatment plant.

CASE STUDY OF STP DELAWAS

Rajasthan Urban Infrastructure Development Project (RUIDP) constructed and commissioned a 62.50 MLD STP at Delawas, Jaipur. The STP is in operation since beginning on its full design capacity.

LAY OUT OF STP

The figure -1 shows the general Layout of STP and figure -2 shows the sewerage coverage area of south zone of Jaipur city from Vidhyadhar Nagar to Pratap Nagar Sanganer. The farthest point is about 25 Km from STP and nearest is 1 Km. from STP. There is no pumping in sewerage network laid up to STP. Main trunk sewer reaching at STP site is 1800 mm in diameter.

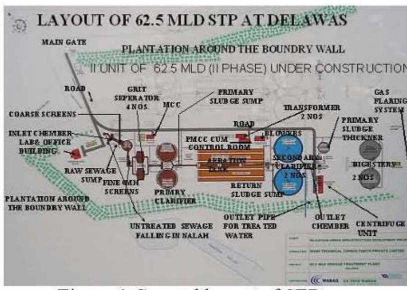


Figure 1 General layout of STP

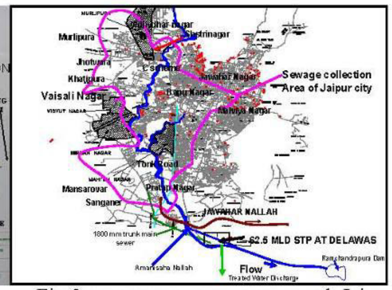


Fig-2-sewerage coverage area south Jaipur

SALIENT FEATURES OF STP

The Plant is based on conventional activated sludge process with diffused aeration system. Sludge is being handled in anaerobic digesters. Digested sludge is pumped to centrifuge unit where it is converted to semi solid form having consistency of 22% solids and used as manure. The salient features of STP are given below in table 1.

Table 1- Salient Features of 62.50 MLD STP

S. No.	Particulars	Details
1.	Capacity: Present I Phase	62.50 MLD
2.	Work cost	Total Rs. 1157.00 lacs in year 2004-05. O&M cost for 5 years is Rs.180 lacs for 5 year O&M
3.	Total land area	Total 28 Hectare, STP constructed in 7.50 Hectare. Remaining area for future expansion.
4.	Process	Activated Sludge Process with anaerobic Digester and centrifuge unit (no sludge drying beds)
5.	Size of main sewer at STP	1800 mm
6.	Design flow on main sewer	Total 125 MLD

The total guaranteed power consumption is 8576 KWh/ day (more than this consumption, the cost is to be borne by the O&M contractor) for treatment of 62.5-63 MLD sewage and daily actual consumption is about 7950-8400 KWh/day indicating an average consumption of 127-134 KWh/MLD of sewage treated or 4.24-4.48 KWh/Kg of BOD removed (Vatech Wabag Ltd., Jaipur, STP site office). This is much lower than the values of 180-225 KWh/MLD reported for conventional ASP based STPs under Yamuna Action Plan at Allahabad of capacities between 60-80 MLD (MoEF, 2009).

To save power, a Variable Frequency Drive (VFD) is provided which is governed through programmed feedback circuit based on Dissolved Oxygen (DO) levels maintained in the bulk aeration reactor. DO analyzer is connected to VFD, the VFD is controlled by signals generated and transferred by the DO Analyzers, in proportion to the dissolved oxygen content in the mixed liquor exits in the aeration tank compartments. The blowers, fitted with VFD to maintain the required dissolved oxygen concentration in the aeration, effectively control the required airflow rate. Aeration is carried out through retrievable type membrane diffusers, placed at the floor level, spanning the entire floor area for uniform distribution of air. A Separate mechanical type excess sludge thickener is provided to concentrate the excess activated sludge to a level of 8% solids through centrifugal action and another gravity sludge thickener is used to thicken the primary sludge to a similar consistency. Man Machine Interface is provided through PLC System, which controls all operations except those on the Gates, some valves and the F/M ratio. The STP including sludge handling units is functioning on full designed capacity.

OPERATION AND MAINTENANCE COST

Operation and Maintenance for 5 years of STP was with M/s Vatech wabag Ltd. Chennai who has constructed the STP. Power Guarantee was obtained for 8576KWH/day by the contractor during throughout the O&M period of 5 years. O&M cost includes the cost of Man power, wear and tear of machinery, chemicals and maintenance of plantation. O&M expenditure of STP for the period 2006-2011 is given in table -2. The per MLD operating cost is about Rs. 26000-28000 to treat municipal up to secondary level.

Table-2 -Operation and Maintenance Cost of STP

O & M Charges of Plant	**Rs. Cost per month**		
For	Power charges /Month	O&M cost / Month*	Total O&M Cost
I year(2006-07)	13.50-14.00 lacs	2.66 lacs	16.16-16.66 lacs
II year(2007-08)	14.00-15.00 lacs	2.82 lacs	16.82-17.82 lacs
III year(2008-09)	15.00-16.00 lacs	2.98 lacs	17.98-18.98 lacs
IV year(2009-10)	16.00-17.50 lacs	3.16 lacs	19.61-20.66 lacs
V year(2010-11)	17.50-19.00 lacs	3.36 lacs	20.86-22.36 lacs

*Price escalation on O&M cost to be paid to contractor is also paid up to contract period (September 2011) as per condition according to RBI Index.
Source: Vatech Wabag Ltd., Jaipur

CHARACTERISTICS OF SEWAGE

The average characteristics of wastewater received at STP and those of the treated wastewater are summarized in table 3, which have been obtained from the records of STP Delawas for a period of Jan-10 to April-12 for composite samples (sample drawn at an interval every 2 hrs. to make composite sample on daily basis).

Table-3: Characteristics of wastewater

S.No.	Month	Q(ML)/day	Monthly average parameters(Influent)				Monthly Average(effluent)			
			BOD_5 (mg/lit)	COD (mg/lit)	TSS (mg/lit)	pH	BOD_5 (mg/lit)	COD (mg/ lit)	TSS (mg/ lit)	pH
1	2	3	4	5	6	7	8	9	10	11
1	January-10	62.00	288.52	561	783	7.43	23	122	38	7.67
2	February-10	61.90	290.20	572	785	7.42	22	124	41	7.61
3	March-10	62.22	296.61	543.61	797.68	7.38	21	120	35	7.79
4	April-10	60.57	297.33	796.53	546.00	7.38	21	120	36	7.789
5	May-10	62.05	295.00	796.27	544.73	7.40	21	123	37	8.05
6	June-10	62.19	295	789	529	7.40	21	116	34	7.55
7	July-10	62.18	295	799	513	7.39	21	120	34	7.79
8	August-10	62.24	296	801	521	7.56	20	121	34	7.87
9	September-10	62.13	292.00	764.27	501.17	7.58	20.3	123	34	7.81
10	October-10	61.95	287	762	500	7.56	21	116	35	7.80
11	November-10	62.04	285	746	502	7.53	21	117	35	7.78
12	December-10	61.95	288	725	510	7.53	20	118	37	7.82
13	January-11	61.36	291.94	723.87	525.94	7.53	20	120.97	35.61	7.81
14	February-11	61.92	290.71	727.43	559.14	7.52	21	123.00	39.32	7.79
15	March-11	61.87	291.45	723.61	577.74	7.53	19	117.68	36.71	7.77
16	April-11	61.91	291.17	718.93	566.60	7.53	20	119.27	38.83	7.72
17	May-11	61.92	291.13	723.61	572.19	7.54	21.39	121.68	40.10	7.70
18	June-11	61.88	289.33	712.27	549.93	7.54	21.17	120.27	40.03	7.69
19	July-11	62.00	270.97	711.74	526.32	7.54	22.42	126.19	40.19	7.72
20	August-11	61.90	276.17	720.53	532.6	7.54	27	150.90	47.81	7.73
21	September-11	61.89	281.50	721.60	553.67	7.54	22	123	40	7.72
22	October-11	61.91	283.71	716.13	570.19	7.54	22	124	40	7.72
23	November-11	61.98	286.33	716.53	567.13	7.53	22.37	124.13	40.50	7.71
24	December-11	61.91	278.87	716.52	559.35	7.53	22.71	125.55	41.32	7.72
25	January-12	61.35	283.87	564.32	750.26	7.53	23	123	42	7.71
26	February-12	61.86	276.90	563.86	743.66	7.53	22	125	41	7.72
27	March-12	61.86	293.55	564.32	750.26	7.53	23	129	41	7.71
28	April-12	62.08	287.33	564.60	768.27	7.53	23	130	42	7.72
	Average (for 28 months)	**61.89**	**288.24**	**698.06**	**596.64**	**7.50**	**21.67**	**119.97**	**41.48**	**7.75**

Source: Vatech Wabag Ltd., Jaipur

The above results show that Plant is functioning satisfactorily except when colored wastewater (from nearby textile and printing Industries of Sanganer) is received. The BOD, COD ratio changes and it affects the biological process to some extent.

ENERGY CONSERVATION AND RECOVERY FROM SEWAGE TREATMENT PLANT

Power consumption accounts for almost 75% of the expenditure on O&M of the plant. The average per day power consumption for operation of STP is 8576 Kwh, which presently amounts to a total electricity bill of about Rs 12-13 lac per month. Energy saving measures have been taken for the plant operation that have resulted in substantial saving in the energy costs as stated above. For sludge handling anaerobic sludge digesters have been constructed and are in operation. The characteristics of gases produced during anaerobic digestion of sludge are given in table 4

Table-4 Test results of biogas produced during sludge digestion

Per day sludge generation					55-60 m3/day
gas generated during anaerobic digestion					5800-6200 Nm3/ day
The Characteristic and Calorific value of produced gases	CH_4 %v/v	CO_2	H_2S	Calorific value Kcal/Nm^3	Samples were collected and got tested by RUIDP at Shriram Test House, New Delhi.
Morning Sample no.1	52.2	35.00	1.02	5025	
Mid day Sample tested no.2	57.5	30.00	1.26	5613	
After noon Sample no.3	54.8	35.00	1.07	5279	
Protocol/Method for analysis	GC-FID	Orsat Apparatus	IS-11255	IS- 14504	

Source: Vatech Wabag Ltd., Jaipur

Produced Gases are collected through HDPE piping arrangement & allowed to pass through Moisture trap, scrubber unit & then collected in membrane made (balloon type) gas holders. Collected gas is then pumped to gas engine where power is generated. The estimation of power generation from the gases is given in table-5.

Table 5: Estimation of power generation from the digester

ITEM	VALUE
Average amount of Gas Generated From One 62.5 MLD Plant(data taken from JMC)	6000M^3/DAY, 250M^3/ hr
Gas consumption for 1000 Kwh	in the range of 1300-1400 Nm^3(depending on the methane in produced gases)
Calorific Value of Gas(based on test results given in table-4)	5000 TO 5600 KCAL/M^3 (Av value 5300 KCAL/ M^3
1000 KCAL=	1.163 Kwh
Total Heat Energy of 250 Nm3 Gas	1325000 KCAL/hr
Total energy in kw hour	1540 Kwh
Efficiency of biogas engine and generator	28 % & 95% respectively
Electrical Energy can be produced	431 say 400 Kwh (9600 unit/day)

Source: Vatech Wabag Ltd., Jaipur

COST VIABILITY OF POWER GENERATION PLANT

Estimated cost of system to generate terminal power output of 9600 KWh/day was Rs.750 lacs in year 2008. Annual maintenance cost is @ 5-5.5% of total invested capital cost of Rs. 750 lacs. Thus expenses for running the plant per KWh are Rs. 2.50. Present Purchase cost of Power is Rs. 6.00 per Kwh. The per KWH cost of electricity is taken as Rs.6.30 for 1st year and Rs. 6.90, Rs 7.6,Rs. 8.3, Rs 9.20 , Rs. 10.10 , Rs.11.10, Rs. 12.20, Rs. 13.40, Rs.14.70 for subsequent years up to 10 years period. Accordingly, cost viability calculations are given in table-6.

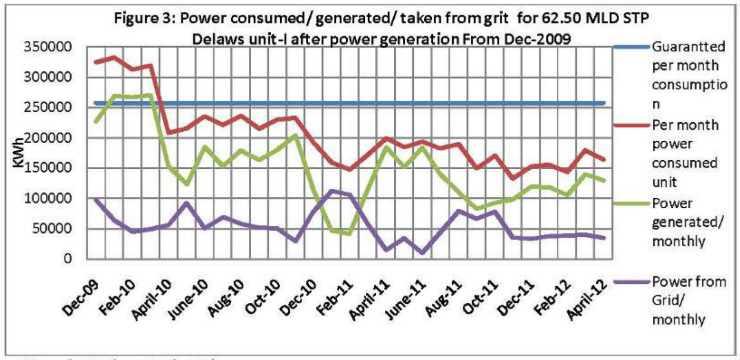
Table 6- Cost viability calculations

Cost Rs. in Lacs.							
Year	Project execution cost	O&M cost /year	Cumulative cost /year	Cumulative interest (@ 15% per year)	Total Exp./ year	Cost of power to be generated /year	Saving/ year
1	2	3	4	5	6=(4+5)	7	8=(6-7)
2008	750.00	30.00	780.00	117.00	897.00	216.71	-680.28
2009	0	30.00	810.00	238.50	1048.50	476.78	-571.71
2010	0	36.00	846.00	365.40	1211.40	786.68	-424.71
2011	0	42.00	888.00	498.60	1386.60	1153.81	-232.78
2012	0	42.00	930.00	638.10	1568.10	1586.48	18.38
2013	0	48.00	978.00	784.80	1762.80	2094.16	331.36
2014	0	48.00	1026.00	938.70	1964.70	2687.51	722.81
2015	0	54.00	1080.00	1100.70	2180.70	3378.58	1197.88
2016	0	54.00	1134.00	1270.80	2404.80	4181.00	1776.20
2017	0	66.00	1200.00	1450.80	2650.80	5110.11	2459.31

As per above analysis the expenditure can be paid back along with compound interest (@ 15%) in 6 years (from Dec-09 to Nov-14) after starting of the power generation unit. Thus, in remaining 3 years (out of ten years O&M period) plant will generate power amounting to approx. 24.59 crores (in terms of money); which can be utilized for other works. About 3.46 crore power units (KWH) can be generated in 10 years period; this power can be gainfully utilized. As per above the pay Back Period is about 6-7 year. If standby unit is not provided thae pay back period will be about 5 years.

STATUS OF POWER GENERATION AND POWER CONSUMPTION AT STP, DELAWAS UNIT-I

The power required for operation of STP, Delawas is coming from two sources; first is from grid and second is from the installed bio gas based power plant (generated bio gas at Unit I which is used for power generation). The total installed power generation capacity is 0.5 (500Kwh) to 1.0 mega watt (1000 Kwh) (including stand by Engine in operation). As per design, daily power consumption in operation process of Unit I is 8987.14 KWh/day and approximately 300 kwh/day is consumed in yard lighting. Figure 3 shows the monthly guaranteed power consumption, actual power consumed, power generated, power taken from grid & monthly power saving at STP, Delawas Unit I:-



Source: Vatech Wabag Ltd., Jaipur

As per Data collected from JMC, prior to the commissioning of power generation unit, the average monthly power consumption was 208653 kWh/month, which was obtained from grid and for which about Rs. 12-14 lacs, monthly payment was made to JVVNL. But after power generation at plant site from December, 2009 to April, 2012, the average power consumed from grid is only 55479 kWh/month. The maximum power consumed in the month of January, 2011 is 112413 KWh/month whereas minimum power consumed in the month of June, 2011 is 9813 KWh/month. Before power generation at plant, total power demand was fulfilled from the grid. Plant was facing major problem of unwanted power cutoff that was directly affected plant operation. But now an average 26% of total power demand is drawn from grid and the rest is met by the power generation at site.

CONCLUSION

The biogases produced at STP delawas contain 52-57% of methane component which is being used to generate electricity of Av. 6500 KWh/ day. The power generation Plant capital cost is about 750 lacs. The O&M cost for Power generation unit is about-2.5-3.00 lacs/ month. The value of generated power is about 14.00-16.00 lacs/ month. This indicates that STP Delawas can be self sufficient in terms of power requirements and operation and maintenance also. Apart from above, at this phase, the treated effluent can be reused for agriculture, forestation, and groundwater recharge or pasture development without further treatment. This would further result in savings of power as pumping of groundwater from deep strata will be reduced in the surrounding area of effluent flow.

Acknowledgement:

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Waste to Energy Sewage Treatment Plant Delawas Jaipur, Rajasthan, India, a Case Study

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Research Article

Abstract: Power consumption accounts for almost 75% of the expenditure on O and M of any sewage treatment plant working on aerobic biological process. STP Delawas, Jaipur based on conventional activated sludge process was commissioned by RUIDP in 2006 with a capacity of 62.5 MLD. The average daily power consumption for operation of STP is 8576 Kwh, which amounted to an electricity bill of more than 1.2 million per month prior to the installation of power generation unit based on biogas fuel. Apart from power generation, energy saving measures taken for the plant operations has resulted in substantial saving in the energy costs. Air blowers are being operated with Variable Frequency Drive (VFD). Man Machine Interface (MMI) is provided through Programmable Logic Control System (PLC) for handling anaerobic sludge digesters that produce about 5800-6500 Nm^3 of gas per day, which is being utilized for power generation. An analysis of three year data shows that the maximum power generated was about 270115 Kwh/month in March, 2010 (Av. 8713 Kwh/day) and lowest 41694 kwh/month in February, 2011(1490 Kwh per day) through gas engine. The value of generated power through biogases is about 1.4-1.66 million/ month (about 75-80% of power requirement) which is a good example of Waste to energy (WTE). This has made the STP almost self sufficient (except for meeting peak hour demand) in terms of power requirements. This study give us a though at the design stage, concept of waste to energy and improvement in efficiency of primary clarifier to get more primary sludge for anaerobic digestion to produce more biogases to get more power which will further reduce the power requirement from grid. The increase in sludge at PST will reduce the BOD load on secondary treatment unit and will help in reduction in power consumption of aeration tank.

Keywords: STP- Sewage Treatment Plant ,BOD5- Biochemical Oxygen, TSS- Total Suspended solids ,ASP- Activated Sludge Process COD-Chemical Oxygen Demand, WTE- Waste to Energy.

Introduction

Sewage treatment is a significant user of energy. Operation of pumps, blowers and other equipment at a typical sewage treatment plant (ASP /extended aeration) per person an annual electrical energy consumption requirement is in the range of 12-19 KWh (Arceivala and Asolekar, 2006). Thus, substantial input of energy is required to treat sewage from densely populated areas, and sewage treatment often comprises the largest use of electricity by local governments. Conventional STPs remove organic content from the water stream by reacting the proteins, fats and carbohydrates with oxygen from the air. This oxidation process is undertaken at ambient temperature by the enzymes secreted by aerobic bacteria and converts most of the organic material to carbon dioxide and water through dissimilatory process. The process also produces sewage sludge, or bio-solids, consisting of un-oxidized organic matter and predominantly bacterial cells. Some treatment plants further reduce the quantity of bio-solids through an anaerobic treatment process. Here, in the absence of air, anaerobic bacteria digest the bio-solids, producing "biogas", a mixture of methane and carbon dioxide. Methane is the main component of natural gas, and the biogas produced, can be burnt in an engine or turbine to produce power and generate electricity. In this way, anaerobic treatment can generate electrical energy used in the sewage treatment plant.

Case Study of STP Delawas

Rajasthan Urban Infrastructure Development Project (RUIDP) constructed and commissioned a 62.50 MLD STP at Delawas, Jaipur. The STP is in operation since beginning on its full design capacity. The STP is in operation since beginning on its full capacity. The figure - 1 shows the sewerage coverage area of south zone of Jaipur city from Vidhyadhar Nagar to Pratap Nagar Sanganer . The farthest point is about 25 Km from STP and nearest is 1 Km. from STP. There is no pumping in sewerage network laid up to STP. Main trunk sewer reaching at STP site is 1800 mm in diameter Figure-2 shows the general Layout of STP. Rs. word is to be added in Table 2, Table 6 (Rs. in million)

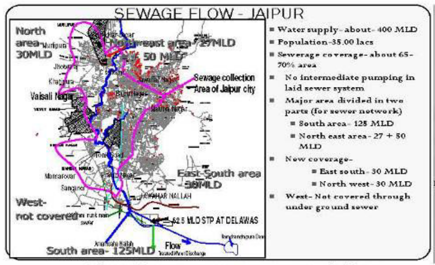

Figure 1: sewerage coverage area south Jaipur

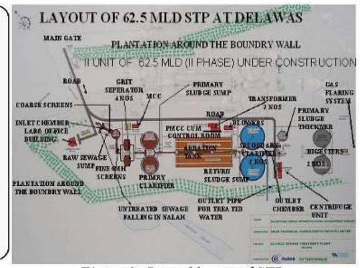

Figure 2: General layout of STP

Salient Features of STP

The Plant is based on conventional activated sludge process with diffused aeration system. Sludge is being handled in anaerobic digesters. Digested sludge is pumped to centrifuge unit where it is converted to semi solid form having consistency of 22% solids and used as manure. The salient features of STP are given below in table1.

Table 1: Salient Features of 62.50 MLD STP

S. No.	Particulars	Details
1.	Capacity: Present I Phase	62.50 MLD
2.	Work cost	Total Rs. 1157.00 lacs in year 2004-05. OandM cost for 5 years is Rs.180 lacs for 5 year OandM
3.	Total land area	Total 28 Hectare, STP constructed in 7.50 Hectare. Remaining area for future expansion.
4.	Process	Activated Sludge Process with anaerobic Digester and centrifuge unit (no sludge drying beds)
5.	Size of main sewer at STP	1800 mm
6.	Design flow on main sewer	Total 125 MLD

The total guaranteed power consumption is 8576 Kwh/ day (more than this consumption, the cost is to be borne by the OandM contractor) for treatment of 62.5-63 MLD sewage and daily actual consumption is about 7950-8400 Kwh/day indicating an average consumption of 127-134 Kwh/MLD of sewage treated or 4.24-4.48 Kwh/Kg of BOD removed (Vatech Wabag Ltd., Jaipur, STP site office). This is much lower than the values of 180-225 Kwh/MLD reported for conventional ASP based STPs under Yamuna Action Plan at Allahabad of capacities between 60-80 MLD (MoEF, 2009). To save power, a Variable Frequency Drive (VFD) is provided which is governed through programmed feedback circuit based on Dissolved Oxygen (DO) levels maintained in the bulk aeration reactor. DO analyzer is connected to VFD, the VFD is controlled by signals generated and transferred by the DO Analyzers, in proportion to the dissolved oxygen content in the mixed liquor exits in the aeration tank compartments. The blowers, fitted with VFD to maintain the required dissolved oxygen concentration in the aeration, effectively control the required airflow rate. Aeration is carried out through retrievable type membrane diffusers, placed at the floor level, spanning the entire floor area for uniform distribution of air. A Separate mechanical type excess sludge thickener is provided to concentrate the excess activated sludge to a level of 8% solids through centrifugal action and another gravity sludge thickener is used to thicken the primary sludge to a similar consistency. Man Machine Interface is provided through PLC System, which controls all operations except those on the Gates, some valves and the F/M ratio. The STP including sludge handling units is functioning on full designed capacity.

Operation and Maintenance Cost

Operation and Maintenance for 5 years of STP was with M/s Vatech wabag Ltd. Chennai who has constructed the STP. Power Guarantee was obtained for 8576Kwh/day by the contractor during throughout the OandM period of 5 years. OandM cost includes the cost of Man power, wear and tear of machinery, chemicals and maintenance of plantation. OandM expenditure of STP for the period 2006-2011 is given in table -2. The per MLD operating cost is about Rs. 26000-28000 to treat municipal up to secondary level.

Table 2: Operation and Maintenance Cost of STP

O and M Charges of Plant	Cost per month (in millions)		
For	Power charges /Month	OandM cost / Month*	Total OandM Cost
I year(2006-07)	1.35-1.40	0.266	1.61-1.66
II year(2007-08)	1.40-1.50	0.282	1.68-1.78
III year(2008-09)	1.50-1.60	0.298	1.80-1.89
IV year(2009-10)	1.60-1.75	0.31	1.96-2.06
V year(2010-11)	1.75-1.90	0.33	2.08-2.23

*Price escalation on O and M cost to be paid to contractor is also paid up to contract period (September 2011) as per condition, according to RBI Index. Source: Vatech Wabag Ltd., Jaipur

Characteristics of Sewage

The average characteristics of wastewater received at STP and those of the treated wastewater are summarized in table 3, which have been obtained from the records of STP Delawas for a period of Jan-10 to April-12 for composite samples (sample drawn at an interval every 2 hrs. to make composite sample on daily basis). The average per day sewage quantity is being treated is in the range of 60.57 MLD (in April-10) -62.24 MLD(in Aug-10) in the period from Jan-10 to April-12 and average per day sewage is 61.89 MLD against designed flow of 61.25 MLD . The average parameters results in above period of influent and effluent are tabulated in table-3

Table 3: Characteristics of wastewater

Parameters	BOD_5 (mg/lit)	COD (mg/ lit)	TSS(mg/ lit)	pH
Designed influent parameters	300	750	600	6-9
Actual average (Influent) parameters	288	698	596	7.50
Designed effluent parameters	30	250	100	6-9
Actual Average (effluent)	21	119	41	7.75

Source: Vatech Wabag Ltd., Jaipur , Note:- values rounded off to nearest integer. The above results show that STP is functioning satisfactorily in terms of achievement of designed effluent parameters.

Energy Conservation and Recovery From Sewage Treatment Plant

Power consumption accounts for almost 75% of the expenditure on OandM of the plant. The average per day power consumption for operation of STP is 8576 Kwh, which presently amounts to a total electricity bill of about 1.2-1.3 million per month. Energy saving measures has been taken for the plant operation that has resulted in substantial saving in the energy costs as stated above. For sludge handling anaerobic sludge digesters have been constructed and are in operation. The characteristics of gases produced during anaerobic digestion of sludge are given in table 4

Table 4: Test results of biogas produced during sludge digestion

Per day sludge generation					55-60 m3/day
gas generated during anaerobic digestion					5800-6200 Nm3/ day
The Characteristic and Calorific value of produced gases	CH_4 %v/v	CO_2	H_2S	Calorific value Kcal/Nm^3	Samples were collected and got tested by RUIDP at Shriram Test House, New Delhi
Morning Sample no.1	52.2	35.00	1.02	5025	
Mid day Sample tested no.2	57.5	30.00	1.26	5613	
After noon Sample no.3	54.8	35.00	1.07	5279	
Protocol/Method for analysis	GC-FID	Orsat Apparatus	IS-11255	IS- 14504	

Source: Vatech Wabag Ltd., Jaipur Produced Gases are collected through HDPE piping arrangement and allowed to pass through Moisture trap, scrubber unit and then collected in membrane made (balloon type) gas holders. Collected gas is then pumped to gas engine where power is generated. The estimation of power generation from the gases is given in table-5.

Table 5: Estimation of power generation from the digester

Item	Value
Average amount of Gas Generated From One 62.5 MLD Plant (data taken from JMC)	6000M^3/DAY, 250M^3/ hr
Gas consumption for 1000 Kwh	in the range of 1300-1400 Nm^3(depending on the methane in produced gases)
Calorific Value of Gas(based on test results given in table-4)	5000 TO 5600 KCAL/M^3 (Av value 5300 KCAL/ M^3
1000 KCAL=	1.163 Kwh

Total Heat Energy of 250 Nm3 Gas	1325000 KCAL/hr
Total energy in kw hour	1540 Kwh
Efficiency of biogas engine and generator	28 % and 95% respectively
Electrical Energy can be produced	431 say 400 Kwh (9600 unit/day)

Source: Vatech Wabag Ltd., Jaipur

Cost Viability of Power Generation Plant

Estimated cost of system to generate terminal power output of 9600 KWh/day was 7.50 million in year 2008. Annual maintenance cost is @ 5-5.5% of total invested capital cost of 7.50 million. Thus expenses for running the plant per Kwh are 2.50. Present Purchase cost of Power is 6.00 per Kwh. The per Kwh cost of electricity is taken as 6.30 for 1st year and 6.90, 7.6, 8.3, 9.20, 10.10, 11.10, 12.20, 13.40, 14.70 for subsequent years up to 10 years period. Accordingly, cost viability calculations are given in table-6.

Table 6: Cost viability calculations

Cost in million.							
Year	**Project execution Cost**	**O and M cost /year**	**Cumulative cost /year**	**Cumulative interest (@ 15% per year)**	**Total Exp./ year**	**Cost of power to be generated /year**	**Cumulative Saving/ year**
1	**2**	**3**	**4**	**5**	**6=(4+5)**	**7**	**8=(7-6)**
2008	7.50	3.00	78.00	11.70	89.7	21.67	-68.03
2009	0	3.00	81.00	23.85	104.85	47.68	-57.17
2010	0	3.60	84.60	36.54	121.14	78.67	-42.47
2011	0	4.20	88.80	49.86	138.66	115.38	-23.28
2012	0	4.20	93.00	63.81	156.81	158.65	1.84
2013	0	4.80	97.80	78.48	176.28	209.42	33.14
2014	0	4.80	102.60	93.87	196.47	268.75	72.28
2015	0	5.40	108.00	110.07	218.07	337.86	119.79
2016	0	5.40	113.40	127.08	240.48	418.1	177.62
2017	0	6.60	120.00	145.08	265.08	511.01	245.93

As per above analysis the expenditure can be paid back along with compound interest (@ 15%) in 6 years (from Dec-09 to Nov-14) after starting of the power generation unit. Thus, in remaining 3 years (out of ten years OandM period) plant will generate cumulative power amounting to approx. 245.90 million (in terms of money); which can be utilized for other works. About 34.60 million power units (Kwh) can be generated in 10 years period; this power can be gainfully utilized. As per above the pay Back Period is about 6-7 year. If standby unit is not provided the payback period will be about 5 years.

Status of Power Generation and Power Consumption At STP Delwas Unit-I

The power required for operation of STP, Delawas is coming from two sources; first is from grid and second is from the installed bio gas based power plant (generated bio gas at Unit I which is used for power generation). The total installed power generation capacity is 0.5 (500Kwh) to 1.0 mega watt (1000 Kwh) (including stand by Engine in operation). As per design, daily power consumption in operation process of Unit I is 8987.14 Kwh/day and approximately 300 kwh/day is consumed in yard lighting. Figure 3 shows the monthly guaranteed power consumption, actual power consumed, power generated, power taken from grid and monthly power saving at STP, Delawas Unit I:-

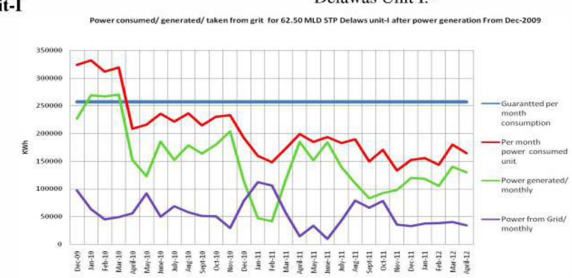

Figure 3: Source: Vatech Wabag Ltd., Jaipur

As per Data collected from JMC, prior to the commissioning of power generation unit, the average monthly power consumption was 208653 Kwh /month, which was obtained from grid and for which about 1.2-1.4 million, monthly payment was made to JVVNL. But after power generation at plant site from December, 2009 to April, 2012, the average power consumed from grid is only 55479 Kwh/month. The maximum power consumed in the month of January, 2011 is 112413 Kwh/month whereas minimum power consumed in the month of June, 2011 is 9813 Kwh/month. Before power generation at plant, total power demand was fulfilled from the grid. Plant was facing major problem of unwanted power cutoff that was directly affected plant operation. But now an average 26% of total power demand is drawn from grid and the rest is met by the power generation at site.

Conclusion

The produced biogases contain 52-57% of methane component which is being used to generate electricity of Av. 6500 KWh/ day. The power generation Plant capital cost is about 750 lacs. The O and M cost for Power generation unit is about 0.25-0.30 million/ month. The value of generated power through biogases is about 1.40-1.60 million/ month which is a good example of Waste to energy (WTE). About 75-80% of required power is being produced thus STP can be made self sufficient in terms of power requirements and operation and maintenance also reuse of treated wastewater for agriculture, forestation, and groundwater recharge or pasture development without further treatment. This would further result in savings of power as pumping of groundwater from deep strata will be reduced in the surrounding area of effluent flow. At the design stage, consideration of waste to energy concept should be considered by the designer to reduce O and M cost of STP and improvement in efficiency of primary clarifier to get more primary sludge and reduce load on secondary treatment unit.

Acknowledgement

T t he authors acknowledge with sincere gratitude the help provided by Mr. P.C. Pandey Laboratory In-charge of STP Delawas, Jaipur as an employee of M/s Vatech Wabg Ltd, for this study.

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4. Paper presented in 46th annual convention of IWWA at Banglore India, in Jan-2014 by the authors.