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DEVELOPMENT OF COST FUNCTIONS FOR WASTEWATER TREATMENT BY SEQUENTIAL BATCH REACTOR

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Highlights:

- the cost functions for WWTPs with SBR for small, medium and large capacities are best expressed by polynomial equations;
- the determination coefficient in respect of cost functions developed for small, medium and large capacities are 1, 0.9886 and 0.9975 respectively;
- the values of Mean Absolute Percentage Error with reference to the cost functions for small, medium and large capacities are 0.32%, 5.35% and 1.68% respectively. In each case, the value of Mean Absolute Percentage Error is found to be within 10%;
- cost functions have been developed based on detail engineering design and cost estimations with due consideration of rates applicable in India. The cost functions are not derived from collected historic cost data-base;
- the approach as adopted and addressed may be followed to develop cost functions applicable for any location in any country across the world either based on use of design & estimation algorithms developed and region specific schedule of rates for precise forecast or adjustment of projected costs by use of applicable factor for conversion of currency.

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Abstract. Sequential batch reactor is widely used for industrial wastewater treatment. To consider sequential batch reactor for biological treatment of wastewater at a specific site, it is essential to ensure economy and sustainability. An approach for scrutiny of economic aspects may be based upon use of cost functions to compare sequential batch reactor and other technologies. Such approach will enable to conduct prudent analysis and select the most economic treatment scheme for a particular project. In most of published studies, the cost functions for conventional wastewater treatment systems are described with historic or some other data available to the investigators. No detailed engineering exercise related to cost functions for sequential batch reactor is cited in earlier research studies. In this document the novel and appropriate methodology has been presented to develop cost functions based on engineering, estimation and statistical approach to forecast cost for sequential batch reactor based wastewater treatment system.

Keywords: cost function, mean absolute percentage error, capacity in mld, SBR, regression analysis, wastewater treatment.

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1. Introduction

Background of the study, short review of the pertinent literature and motivation

In the past decade many urban local bodies and other government authorities have introduced few new technologies for the treatment of wastewater in many cases. Sequential Batch Reactor (SBR) belongs to such new technologies and widely used for biological treatment of municipal and industrial wastewater. Installation of SBR reduces the requirements for acquisition of land areas, optimizes cost of operation as well as maintenance and improves the quality of effluent particularly for ammonia rich wastewater feed. Footprint requirement in respect of SBR for wastewater treatment is lower compared to that for conventional activated sludge process (ASP) (Central Public Health and Environmental Engineering Organization in collaboration with JICA, 2013). To consider SBR for biological treatment of wastewater at a specific site, it is essential to ensure economy and sustainability. Such a necessity calls for economic comparisons among SBR and several other alternative options for secondary treatment of wastewater. An approach for scrutiny of economic aspects may be the use of appropriate cost functions derived based on standard engineering design rationale, cost estimation for construction as well as requirement of space, operation and maintenance to compare sequential batch reactor and other technologies. Such approach will enable to conduct prudent analysis and select the most economic technology for a particular project. From literature review, it has been noted that several studies were undertaken to develop cost functions and cost indices for estimation of construction cost and operation cost of WWTSs (U.S. Environmental Protection Agency [USEPA], 1976; Gumerman et al., 1978; Qasim et al., 1992; Vanrolleghem et al., 1996; Gillot et al., 1999; Fraquelli & Giandrone, 2001; Nogueira et al., 2007; Singhirunnusorn & Stenstrom, 2010; Yengejeh et al., 2014; Arif et al., 2020). Arif et al. (2020) applied economic modelling to explore the most economic treatment among three WWTSs based on continuously mixed activated sludge with pre-denitrification as well as without denitrification and Membrane Bio Reactor (MBR) with the help of CapdetWorks simulation software for an average flow of 30 mld (Arif et al., 2020). Friedler and Pisanty (2006) have developed cost functions by analysis of the costs of 55 WWTSs constructed in Israel (Friedler & Pisanty, 2006). Dysert (2008) pointed out that parametric cost models may be important resource for early estimates (Hernandez-Sancho et al., 2011). Pannirselvam and Navaneetha Gopalakrishnan (2015) compiled the cost records for thirty WWTSs under operation which were built with conventional activated sludge technology. Cost data were adjusted with reference to the year 2014 by use of applicable cost indices. Cost functions were developed by regression analysis (Pannirselvam & Navaneetha Gopalakrishnan, 2015). Gautam et al. (2017) made comparative scrutiny among MBR, Moving Bed Biofilm Reactor (MBBR), SBR, Extended Aeration and Submerged Aerobic Fixed Film Process based few small size WWTSs in India and derived cost functions for capital, electro-mechanical, electricity, operation and maintenance from collected data (Gautam et al., 2017).

Most of the existing literatures pertaining to the theme of this article are described with historic or some other data available to the earlier workers on WWTSs. Estimate based on historic as well as collected cost data may include several factors like different input wastewater quality, treated water quality, design basis, locations, schedule of rates which may induce errors in comparative analysis. Use of CapdetWorks software in few studies has been made for cost comparison among few technologies (Arif et al., 2020; Jafarinejad, 2017). Conventional technologies like activated sludge, oxidation ditches and few others have been taken into account by the researchers in majority of the investigations. Studies on cost functions formulated through engineering design and estimations for treatment of wastewater are sparse as per the literatures available. Cost function developed based on engineering design and estimate in appropriate manner will yield fairly accurate estimate. Further no detailed exercise related to cost functions for WWTS with space-saving technologies like SBR is cited in earlier research studies. These gaps as noticed from scrutiny of literatures motivated the authors to develop the cost functions for WWTS with SBR technology based on engineering rationale as a part of initiatives to develop a set of cost functions as tools based on proper engineering design and fairly accurate estimation for different technologies with reference to secondary biological treatment of wastewater.

Originality or novelty of the research

A novel initiative has been adopted for development of cost functions for WWTS with SBR technology with due consideration of cost of land acquisition. The approach is based on engineering design and cost estimation rather than use of historic and available cost database. Process design, determination of bill of quantities and cost estimation as per published schedule of rates are the base for development of the cost functions. This approach is envisaged to be appropriate and reliable for cost comparison between SBR and other technologies with reference to planning for installation of WWTS. Exercise with this novel approach will enrich the domain of cost functions for use by engineers and urban management authorities with reference to selection of secondary treatment technology in WWTS. In this paper, methodologies used to develop cost functions for removal of BOD by SBR have been discussed. These functions will enable estimation of cost for construction of SBR based WWTS for any capacity within a broad range and its operation for a design life of twenty five years. It is believed that the derived cost functions will assist stakeholders to arrive at a prudent decision on technology for WWTS.

Objectives of the research

The objective of subject investigation is not the optimization of the biotechnological process, but rather to obtain a suitable biological process selected from the cost point of view keeping the end parameters in conformity with statutory standards with respect to input characteristics of prevailing wastewater from city. The cost function is chosen to explore the criteria of owner and contractor competing for the award of a project.

For WWTSs, preliminary treatment and sludge handling systems are more or less similar irrespective of the kind of secondary or biological treatment as envisaged. Therefore the technology adopted for secondary treatment will control the cost for construction and operation of a WWTS. With reference to this scenario, the objective of this study has been based on design and cost estimation for secondary treatment only. Cost estimation for preliminary treatment and sludge handling systems has not been taken into consideration to develop the cost functions for WWTS with SBR. This study on cost functions is based upon the detailed engineering and cost estimations of secondary treatment with SBR technology for wastewater. Cost functions derived will provide quick and accurate cost estimation for WWTS with SBR technology. These will also enable to avoid the trend of use of collected or available cost data for selection of technology with reference to biological treatment of wastewater.

2. Methodology and theoretical framework

2.1. Capacity

The ranges for capacity of WWTS as envisaged are furnished below:

a) Low range of 0.5 mld to 5 mld.
b) Medium range of 5 mld to 50 mld.
c) Large range of 50 mld to 150 mld.

2.2. Raw wastewater characteristics

The design characteristics as envisaged are presented in Table 1 (Central Public Health and Environmental Engineering Organization in collaboration with JICA, 2013). Concentrations are based on water supply @ 135 lit/cap/day (Central Public Health and Environmental Engineering Organization in collaboration with JICA, 2013).

Table 1. Raw wastewater characteristics

Impurities	Unit	Content
BOD (biochemical oxygen demand)	mg/l	250.00
COD (chemical oxygen demand)	mg/l	425.00
TSS (total suspended solids)	mg/l	375.00

The cost function for a specific input flow rate shall be sensitive to inlet BOD load in wastewater. The cost functions as developed and discussed in this paper are based on inlet BOD load of 250 g/m^3. Such consideration has been made to develop cost functions for a quality which is most prevalent at/followed for municipal outfall.

2.3. Treated wastewater characteristics

The target objectives are presented in Table 2.

Table 2. Treated wastewater characteristics

Impurities	Unit	Content
BOD	10.00	mg/l
TSS	10.00	mg/l

The requirements of characteristics of treated wastewater are statutory and the same need to be complied in each case.

2.4. Treatment processes

Facts of use of different technologies in wastewater treatment system (WWTS) within India are furnished below as reference:

Table 3. Different technologies in WWTSs (source: Central Pollution Control Board, 2021)

Sl. No.	Technology	Capacity in million liters per day (mld)	Number of WWTSs
1.	Activated sludge process	9486	321
2.	Extended aeration	474	30
3.	Fluidised aerobic bio-reactor	242	21
4.	Moving bed biofilm reactor	2032	201
5.	Oxidation pond	460	61
6.	SBR	10638	490
7.	Up-flow anaerobic sludge blanket	3562	76
8.	Waste stabilization pond	789	67
9.	Other technologies	8497	364

SBR is an improvement of ASP. In case of ASP, primary clarifier, an aeration tank and then a secondary clarifier are required for treatment of wastewater whereas in the SBR, the aeration and settling are carried out in sequential manner within a single tank. Primary clarifiers are not required to be provided. As a minimum two SBR basins are needed for parallel operation such that one is in aeration phase and the other in settling phase for subsequent decantation of the supernatant. Major benefits which may be achieved by use of SBRs are furnished below:

- Primary clarification, biological treatment and secondary clarification take place in single chamber.
- Wide flexibility for smooth operation and control.
- Requirement of minimal area for installation.
- Significant reduction with reference to requirement of capital cost due to elimination of primary and secondary clarifiers and other equipment.

2.5. Rationales for process design of SBR

The rationales as envisaged for process design of SBR are presented in Table 4 (Metcalf & Eddy, Inc., 2003)

Table 4. Rationales for process design of SBR

Design rationale	Unit	Data
Aeration α factor for BOD removal		0.50
Atmospheric pressure at elevation of site	kPa	95.60
Clean water oxygen transfer efficiency (for fine bubble ceramic diffusers)	%	35.00
Concentration of dissolved oxygen at standard conditions	mg/l	9.08
Content of BOD in centrate from sludge dewatering return	mg/l	380.00
Content of BOD in thickener overflow return	mg/l	500.00
Density of air	kg/m^3	1.20
Design effective liquid height in reactor basin	m	4.07
Design factor for lean condition		0.45
Design factor for peak condition		2.25
Elevation at site	m	9.00
Endogenous decay co-efficient	(g VSS/g VSS)/d	0.06
Factor of safety		2.00
Fouling factor for diffuser		0.90
Fraction of biomass as cell debris		0.15
Fraction of plant flow as sludge dewatering centrate		0.0060
Fraction of plant flow as thickener overflow return		0.15
Half velocity constant	g bs COD/m^3	20.00
MLSS	mg/l	4000.00
MLVSS	mg/l	2800.00
Oxygen consumption	mg/mg of cell	1.42
Oxygen transfer efficiency	%	8.00

End of Table 4

Design rationale	Unit	Data
Percentage of oxygen in air (by weight)	%	23.20
Point of air release from bottom of reactor basin	m	0.50
Ratio of BOD_5 to BOD_u		0.67
Ratio of BOD_u to VSS		1.42
Ratio of VSS to TSS		0.70
Salinity & surface tension correction factor for BOD removal		0.95
Specific bacterial growth rate (maximum)	(g VSS/g VSS)/d	6.00
Standard temperature	deg C	20.00
Temperature activity co-efficient:		
Temperature for kinetic parameters	deg C	20.00
Temperature within reactor basin	deg C	12.00
True yield co-efficient	g VSS/g b COD	0.3125
	g VSS/g BOD	0.5000
Value for k_d		
Value for K_s		
Value for μ_m		

2.6. Items for WWTSs

The items and accessories as required for WWTS with SBR are delineated below:

a) Reaction Basins along with accessories.
b) Waste Transfer Pumps for Reactor Basin.
c) Waste Transfer Pump-House for Reactor Basin.
d) Blowers.
e) Blower Building.

Clarifiers (both primary as well as secondary) are not required for SBR based WWTS.

2.7. Design, detailing and cost estimation

A model for design and estimations has been developed in Microsoft Excel Spread Sheets. The model is based on the design input quality of wastewater, design treated quality of wastewater and design parameters as described above. Standard engineering procedures as per classical text book (Metcalf & Eddy, Inc., 2003) have been introduced in the model to determine the sizes of different equipment required for biological treatment in SBR. Algorithms as illustrated in CAPDET – USEPA (Harris et al., 1982) for selection of number of treatment streams for any specific capacity and determination of bill of quantities as suggested for basins with diffused aeration, pumping and blowers have also been introduced in the model to find out the schedule of quantities for different items. Finally costs have been estimated through the model based on schedule of rates for scheduled components of civil works (Public Works Department, Government of India, 2021) and quotations collected for non-scheduled items (mechanical and electrical). Contingency @ 10% has been included in the model to encompass the cost for process control, piping, painting, etc.

The model is developed to perform the following tasks:

a) Determination of quantity and dimensions for individual equipment based on process design.
b) Estimate of quantity for construction of each individual equipment.
c) Estimation of cost of civil, mechanical and electrical items for each individual equipment.
d) Estimation of construction cost of the complete system.
e) Determination of operation as well as maintenance costs for twenty five years of operation.
f) Determination of space required for installation of the WWTS with SBR.

The model is suitable to determine the life cycle cost (costs for land, construction, operation and maintenance) with reasonable accuracy for WWTS with SBR based on inputs for capacity, inlet BOD and allowable outlet BOD.

3. Results of the research

Process design, estimation of bill of quantities for the designed components, cost estimation for each of components for biological treatment with reference to small group [at each of the capacities – 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 & 5.0 mld], medium group [at each of the capacities – 5.0, 10.0, 15.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0 & 50.0 mld] and large group [at each of the capacities – 50.0, 60.0, 70.0, 80.0, 90.0, 100.0, 110.0, 120.0, 130.0, 140.0 & 150.0 mld] have been determined by means of the developed model. A summary of data obtained for small, medium and large groups are displayed in Appendix – Table A1, Table A2 and Table A3.

4. Discussion and interpretation of results obtained

Estimate of costs of construction inclusive of space required for installation, operation as well as maintenance for a design period of twenty five years for WWTS with SBR technology are determined by the model developed. Estimation has been made for each of different groups, Cost curves with capacity in mld along the abscissa and overall costs of WWTSs in ₹ (crore)] along the ordinate have been mapped. Regression technique has been applied for analysis of the results. Based on maximum value of co-efficient of determination (R^2), the most suitable cost response curve among several available trends has been selected for each group and the curves are presented in Figures 1, 2 and 3.

Validation by determination of mean absolute percentage error for each cost function developed has been carried out to check for accuracy.

Mean absolute percentage error is determined by the expression given below:

$$\text{Mean absolute percentage error} = \sum\{(|C_E - C_{CF}| / C_E) \times 100\} / N_{CD},$$

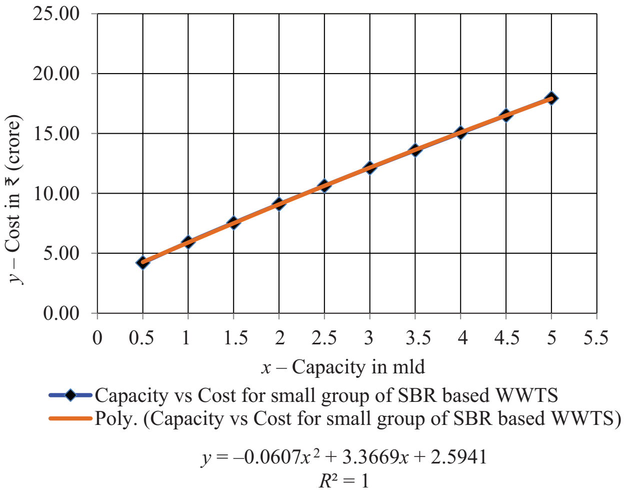

Figure 1. Cost response map for small group of WWTS

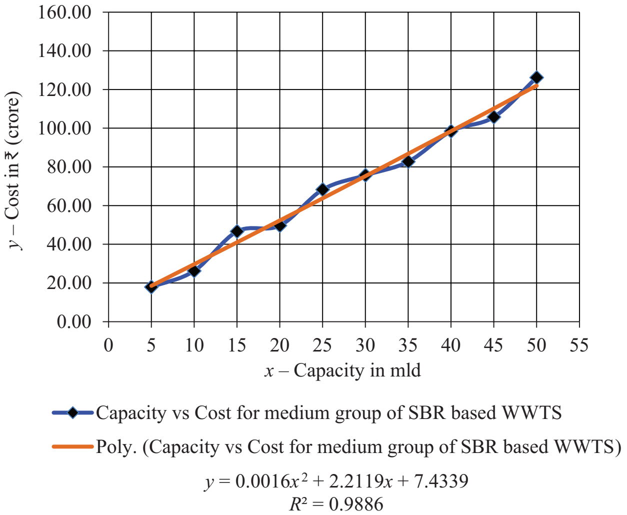

Figure 2. Cost response map for medium group of WWTS

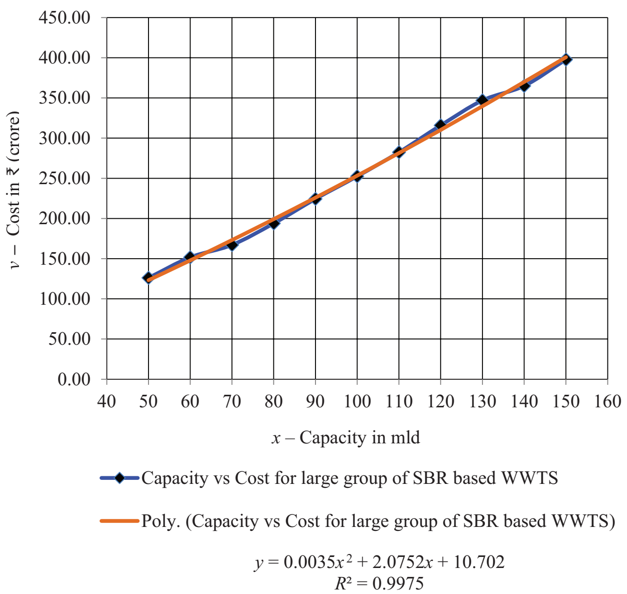

Figure 3. Cost response map for large group of WWTS

where C_E = Cost as estimated through model; C_{CF} = Cost as determined by cost function developed; N_{CD} = Number of cost data considered for validation.

The significance of mean absolute percentage error with reference to its value is delineated below in Table 5:

Table 5. Significance of mean absolute percentage error

Significance	Value of mean absolute percentage error
Excellent forecast	Less than 10
Good forecast	In between 10 to 20
Fair forecast	In between 20 to 50
Inaccurate forecast	>50

The developed cost functions for small, medium and large capacity groups are furnished in Table 6.

Table 6. Developed cost functions for WWTSs with SBR

Description	Cost function	Coefficient of determination (R^2)	Mean absolute percentage error
Small group of WWTSs with SBR (capacity: 0.5 mld to 5 mld)	$CF_{SG} = -0.0607 \times (Q_{SG}^2) + 3.3669 \times Q_{SG} + 2.5941$	1	0.32
Medium group of WWTSs with SBR (capacity: 5 mld to 50 mld)	$CF_{MG} = 0.0016 \times (Q_{MG}^2) + 2.2119 \times Q_{MG} + 7.4339$	0.9886	5.35
Large group of WWTSs with SBR (capacity: 50 mld to 150 mld)	$CF_{LG} = 0.0035 \times (Q_{LG}^2) + 2.0752 \times Q_{LG} + 10.702$	0.9975	1.68

Note: where
CF_{SG} Cost in ₹ (crore) for a WWTS with SBR included under small group;
Q_{SG} Capacity in mld for a WWTS with SBR included under small group;
CF_{MG} Cost in ₹ (crore) for a WWTS with SBR included under medium group;
Q_{MG} Capacity in mld for a WWTS with SBR included under medium group;
CF_{LG} Cost in ₹ (crore) for a WWTS with SBR included under large group;
Q_{LG} Capacity in mld for a WWTS with SBR included under medium group.

It appears from above that cost function for WWTS with SBR for any of the three groups is polynomial in nature. Mean absolute percentage error for each cost function is well below 10% and signifies excellent accuracy.

A comparative analysis has been made for a specific capacity of WWTP with SBR technology with reference to existing approaches/a real case study in order to establish the validity of the methodology of cost estimation discussed in this paper/proposed cost functions in practical applications. For construction of 27 MLD Capacity Sewerage Treatment Plant, a Detailed Project Report (PPD & Sewerage Circle Kozhikode, 2021) had been prepared by PPD & Sewerage Circle Kozhikode – India. In this report, the capital cost of SBR basins has been estimated as 15.0 crores (approximate value) with base year as 2018. With average 8% increase in unit cost every year, the estimated cost with base year 2021 works out as 18.9 crores. As per the estimation model developed by the authors, the estimated capital cost of SBR with base year 2021 works out around 19.0 crores (reference page 4 of 7: Appendix – Table A2). Thus there is a variation of estimated cost within 1% with reference to that for a real case. Therefore it is evident that methodologies of cost estimation/cost functions developed are quite accurate and applicable for practical cases.

5. Conclusions

Cost functions for WWTSs with SBR have been developed with applicable engineering design rationale and do not bear any historic reference. These are found to be accurate. These functions will predict overall cost inclusive of capital, operation and maintenance expenditure for WWTSs with SBR technology within the specified ranges of capacity. Use of these cost functions for tentative forecast at any place other than India is possible subject to adjustment based on the schedule of rates and quotes for non-scheduled items as applicable for the specific place or use of applicable factor for conversion of currency.

It is noteworthy here that cost estimation as discussed in this paper are based on Schedule of Rates (latest publication) of Public Works Department (PWD), Government of India (2021) for civil items and rates collected from reputed vendors for non-scheduled items (mechanical and electrical). Cost index is a numerical factor used to arrive at a realistic figure for a certain City and for a certain Time Line to make the estimation case specific. Applicable cost indices need to be multiplied with the cost derived based on cost function to obtain the estimated cost at a particular time and place in India. Further the cost derived based on cost function represents the investment required for the list of equipment addressed in the paper for biological treatment only as discussed under "Objectives of the research". Costs of other equipment and accessories for preliminary treatment and sludge handling system as applicable for a specific project need to be added to arrive at the overall project cost.

Further research study need to be taken up to study cost response for variation in inlet BOD based on rational methodology with engineering and cost estimations as adopted to develop cost functions for biological treatment of wastewater with SBR technology in terms of capacity. Methodology may also be applied to other technologies in practice. Authors have worked out and published papers on MBR technology and MBBR technology. Such research initiatives would enrich the domain of applicable cost functions with engineering base.

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Author contributions

Bhaskar Sengupta did execute the process design and estimations of cost based on the model developed in Microsoft Excel, analyze the results, develop the cost functions and prepare this manuscript. The manuscript has been reviewed and approved by Dr. Abhisek Roy and Dr. Somnath Mukherjee.

Disclosure statement

There is no conflict of interest in respect of preparation of this manuscript.

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APPENDIX

Table A1. Summary of results derived for small group of WWTSs with SBR technology

DESIGN SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – SMALL GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Design parameter	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
Influent flow rate	m^3/d	578.00	1156.00	1734.00	2312.00	2890.00	3468.00	4046.00	4624.00	5202.00	5780.00
Average BOD load	kg/d	163.64	327.28	490.92	654.56	818.20	981.84	1145.48	1309.12	1472.76	1636.40
Number of reaction basins	number	2	2	2	2	2	2	2	2	2	2
Fill time	h	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Reaction time	h	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Design time selected for aeration	h	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Settlement time	h	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Decantation time	h	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Total cycle time	h	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Solids residence time – design value	d	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10
Total volume of each reaction basin	m^3	289.00	578.00	867.00	1156.00	1445.00	1734.00	2023.00	2312.00	2601.00	2890.00
Fill volume per cycle per reaction basin	m^3	72.25	144.50	216.75	289.00	361.25	433.50	505.75	578.00	650.25	722.50
Selected value for (fill volume/total volume of reaction basin)	ratio	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Decant depth	m	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Total liquid depth when full	m	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07
Mixed liquor suspended solids (X_{MLSS})	$g.m^3$	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00
Mixed liquor volatile suspended solids (X_{MLVSS})	$g.m^3$	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64
DESIGN SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – SMALL GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Design parameter	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
F/M	(g BOD/d)/g VSS	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Volumetric BOD loading	$(kg BOD/d)/m^3$	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Decant pumping rate	m^3/min	2.41	4.82	7.23	9.63	12.04	14.45	16.86	19.27	21.68	24.08
Total TSS purged per day	kg MLSS/d	143.59	287.17	430.76	574.34	717.93	861.52	1005.10	1148.69	1292.27	1435.86
Observed yield based on VSS	g VSS/g BOD	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Observed yield based on TSS	g TSS/g BOD	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Oxygen demand per reaction basin	kg oxygen/d	93.12	186.25	279.37	372.50	465.62	558.75	651.87	744.99	838.12	931.24
Total aeration time per day per reaction basin		8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Average oxygen transfer rate per reaction basin	kg oxygen/h	11.64	23.28	34.92	46.56	58.20	69.84	81.48	93.12	104.76	116.41
Concentration of BOD in effluent	g/m^3	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66
Concentration of TSS in effluent	g/m^3	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

Continued Table A1

EQUIPMENT SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – SMALL GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Description	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
Number of batteries		1	1	1	1	1	1	1	1	1	1
REACTION BASINS & ACCESSORIES											
Number of reaction basins		2	2	2	2	2	2	2	2	2	2
Length of each reaction basin	m	7.76	15.52	23.28	31.05	38.81	46.57	54.33	62.09	69.85	77.62
Width of each reaction basin	m	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14
Depth of each reaction basin	m	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Number of swing arm headers of each reaction basin		2	3	5	6	8	9	11	12	14	15
REACTOR BASIN WASTE TRANSFER PUMPS AND PUMP-HOUSE											
Total number of pumps required		2	2	2	2	2	2	2	2	2	2
Capacity of each pump	m^3/h	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Area required for pump-house	m^2	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
BLOWERS AND BLOWER BUILDING											
Total number of blowers required		2	2	2	2	2	2	2	2	2	2
Capacity of each blower	scfm	360.00	720.00	1080.00	1440.00	1800.00	2160.00	2519.00	2879.00	3239.00	3599.00
Area required for blower building	m^2	54.00	65.00	72.00	77.00	82.00	85.00	89.00	92.00	95.00	97.00
ESTIMATED COST SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – SMALL GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Description	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
REACTION BASINS & ACCESSORIES											
Total bare construction cost (CAPEX)	Crore ₹	0.50	0.79	1.08	1.39	1.71	2.03	2.35	2.66	2.99	3.30
Levelized cost based on energy requirement, operation and maintenance for 25 years of life of reaction basins and accessories (OPEX)	Crore ₹	1.03	1.71	2.37	3.02	3.66	4.29	4.91	5.53	6.15	6.77
Overall cost inclusive of CAPEX & OPEX	Crore ₹	1.53	2.50	3.45	4.41	5.37	6.31	7.26	8.20	9.14	10.08
REACTOR BASIN WASTE TRANSFER PUMPS AND PUMP-HOUSE											
Total bare construction cost (CAPEX)	Crore ₹	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Levelized cost based on energy requirement, operation and maintenance for 25 years of life of pumps and pump-house (OPEX)	Crore ₹	0.16	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.24	0.25
Overall cost inclusive of CAPEX & OPEX	Crore ₹	0.81	0.82	0.84	0.85	0.86	0.87	0.88	0.88	0.89	0.90
BLOWERS AND BLOWER BUILDING											
Total bare construction cost (CAPEX)	Crore ₹	1.10	1.53	1.86	2.15	2.41	2.64	2.86	3.07	3.26	3.45

Continued Table A1

ESTIMATED COST SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – SMALL GROUP											
BOD REMOVAL											
		Capacity in mld	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**
		0.5	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
Description	**Unit**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
ESTIMATED CONSOLIDATED COSTS											
Total bare construction cost (CAPEX)	Crore ₹	2.25	2.96	3.60	4.19	4.77	5.32	5.86	6.38	6.90	7.40
Levelized cost based on energy requirement, operation and maintenance for 25 years of life of STP	Crore ₹	1.19	1.89	2.56	3.22	3.87	4.50	5.14	5.77	6.40	7.03
Overall cost inclusive of CAPEX & OPEX	Crore ₹	3.45	4.85	6.15	7.41	8.64	9.82	11.00	12.15	13.30	14.42
COST OF LAND											
Cost of land	Crore ₹	0.77	1.08	1.39	1.70	2.00	2.31	2.61	2.91	3.22	3.52
OVERALL COST											
Overall cost inclusive of CAPEX & OPEX	Crore ₹	4.21	5.93	7.54	9.11	10.64	12.13	13.61	15.06	16.51	17.94
Overall cost inclusive of CAPEX & OPEX	Million $	0.53	0.74	0.94	1.14	1.33	1.52	1.70	1.88	2.06	2.24
REGRESSION ANALYSIS AND DETERMINATION OF MAPE – SMALL GROUP											
BOD REMOVAL											
		Capacity in mld	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**
		0.5	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
Description	**Unit**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
Predicted value (as per exponential cost function)	Crore ₹	5.21	6.06	7.05	8.21	9.55	11.11	12.93	15.05	17.51	20.38
Value of R^2		0.9487									
Absolute percentage error	%	23.65	2.19	6.49	9.87	10.24	8.38	4.98	0.08	6.04	13.56
MAPE	%	8.55									
Predicted value (as per linear cost function)	Crore ₹	4.44	5.96	7.48	8.99	10.51	12.03	13.54	15.06	16.58	18.09
Value of R^2		0.9993									
Absolute percentage error	%	5.50	0.50	0.87	1.23	1.21	0.85	0.49	0.00	0.39	0.84
MAPE	%	1.19									
Predicted value (as per logarithmic cost function)	Crore ₹	2.19	6.36	8.79	10.52	11.86	12.96	13.89	14.69	15.40	16.03
Value of R^2		0.9202									
Absolute percentage error	%	48.02	7.16	16.58	15.56	11.51	6.84	2.03	2.46	6.76	10.66
MAPE	%	12.76									

End of Table A1

REGRESSION ANALYSIS AND DETERMINATION OF MAPE – SMALL GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Description	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
Predicted value (as per polynomial cost function)	Crore ₹	4.26	5.90	7.51	9.09	10.63	12.15	13.63	15.09	16.52	17.91
Value of R^2		1									
Absolute percentage error	%	1.18	0.53	0.46	0.23	0.07	0.15	0.18	0.20	0.02	0.18
MAPE	%	0.32									
Predicted value (as per power cost function)	Crore ₹	3.92	6.10	7.91	9.51	10.97	12.33	13.61	14.83	15.99	17.10
Value of R^2		0.9924									
Absolute percentage error	%	7.02	2.92	4.92	4.48	3.15	1.68	0.02	1.55	3.18	4.68
MAPE	%	3.36									

Table A2. Summary of results derived for medium group of WWTSs with SBR technology

DESIGN SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – MEDIUM GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		5	10	15	20	25	30	35	40	45	50
Design parameter	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
Influent flow rate	m^3/d	5780.00	11560.00	17340.00	23120.00	28900.00	34680.00	40460.00	46240.00	52020.00	57800.00
Average BOD load	kg/d	1636.40	3272.80	4909.20	6545.60	8182.00	9818.40	11454.80	13091.20	14727.60	16364.00
Number of reaction basins	number	2	3	4	6	7	8	9	11	12	13
Fill time	h	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Reaction time	h	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Design time selected for aeration	h	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Settlement time	h	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Decantation time	h	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Total cycle time	h	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Solids residence time – design value	d	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10
Total volume of each reaction basin	m^3	2890.00	3853.33	4335.00	3853.33	4128.57	4335.00	4495.56	4203.64	4335.00	4446.15
Fill volume per cycle per reaction basin	m^3	722.50	963.33	1083.75	963.33	1032.14	1083.75	1123.89	1050.91	1083.75	1111.54
Selected value for (fill volume/total volume of reaction basin)	ratio	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Decant depth	m	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Total liquid depth when full	m	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07
Mixed liquor suspended solids (X_{MLSS})	$g.m^3$	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00
Mixed liquor volatile suspended solids (X_{MLVSS})	$g.m^3$	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64

Continued Table A2

DESIGN SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – MEDIUM GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		5	10	15	20	25	30	35	40	45	50
Design parameter	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
F/M	(g BOD/d)/g VSS	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Volumetric BOD loading	(kg BOD/d)/m^3	0.57	0.85	1.13	1.70	1.98	2.26	2.55	3.11	3.40	3.68
Decant pumping rate	m^3/min	24.08	32.11	36.13	32.11	34.40	36.13	37.46	35.03	36.13	37.05
Total TSS purged per day	kg MLSS/d	1435.86	2871.72	4307.58	5743.44	7179.29	8615.15	10051.01	11486.87	12922.73	14358.59
Observed yield based on VSS	g VSS/g BOD	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Observed yield based on TSS	g TSS/g BOD	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Oxygen demand per reaction basin	kg oxygen/d	931.24	1241.66	1396.86	1241.66	1330.35	1396.86	1448.60	1354.53	1396.86	1432.68
Total aeration time per day per reaction basin	h	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Average oxygen transfer rate per reaction basin	kg oxygen/h	116.41	155.21	174.61	155.21	166.29	174.61	181.07	169.32	174.61	179.08
Concentration of BOD in effluent	g/m^3	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66
Concentration of TSS in effluent	g/m^3	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
EQUIPMENT SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – MEDIUM GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		5	10	15	20	25	30	35	40	45	50
Description	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
Number of batteries		1	1	1	1	1	1	1	1	1	1
REACTION BASINS & ACCESSORIES											
Number of reaction basins		2	3	4	6	7	8	9	11	12	13
Length of each reaction basin	m	77.62	103.49	116.42	103.49	110.88	116.42	120.74	112.90	116.42	119.41
Width of each reaction basin	m	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14
Depth of each reaction basin	m	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Number of swing arm headers of each reaction basin		15	20	45	40	65	68	70	88	90	116
REACTOR BASIN WASTE TRANSFER PUMPS AND PUMP-HOUSE											
Total number of pumps required		2	2	2	2	2	2	2	2	2	2
Capacity of each pump	m^3/h	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Area required for pump-house	m^2	60.00	60.00	61.00	61.00	61.00	61.00	61.00	62.00	62.00	62.00
BLOWERS AND BLOWER BUILDING											
Total number of blowers required		2	2	3	3	4	4	4	4	4	5
Capacity of each blower	scfm	3599.00	4798.00	5398.00	4798.00	5141.00	5398.00	5598.00	6979.00	7197.00	6921.00
Area required for blower building	m^2	97.00	105.00	129.00	125.00	141.00	143.00	144.00	152.00	154.00	164.00

Continued Table A2

ESTIMATED COST SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – MEDIUM GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		5	10	15	20	25	30	35	40	45	50
Description	**Unit**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
REACTION BASINS & ACCESSORIES											
Total bare construction cost (CAPEX)	Crore ₹	3.30	5.99	10.69	13.12	17.64	20.65	23.61	28.78	31.95	38.02
Levelized cost based on energy requirement, operation and maintenance for 25 years of life of reaction basins and accessories (OPEX)	Crore ₹	6.77	9.12	19.00	17.58	26.95	28.50	29.79	36.66	38.02	47.82
Overall cost inclusive of CAPEX & OPEX	Crore ₹	10.08	15.11	29.69	30.70	44.58	49.15	53.40	65.43	69.97	85.84
REACTOR BASIN WASTE TRANSFER PUMPS AND PUMP-HOUSE											
Total bare construction cost (CAPEX)	Crore ₹	0.65	0.65	0.65	0.65	0.66	0.66	0.66	0.66	0.66	0.67
Levelized cost based on energy requirement, operation and maintenance for 25 years of life of pumps and pump-house (OPEX)	Crore ₹	0.25	0.28	0.39	0.37	0.47	0.48	0.49	0.56	0.57	0.68
Overall cost inclusive of CAPEX & OPEX	Crore ₹	0.90	0.93	1.04	1.02	1.13	1.14	1.15	1.23	1.24	1.34
BLOWERS AND BLOWER BUILDING											
Total bare construction cost (CAPEX)	Crore ₹	3.45	4.01	6.11	5.73	7.68	7.89	8.06	9.12	9.28	11.11
ESTIMATED COST SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – MEDIUM GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		5	10	15	20	25	30	35	40	45	50
Description	**Unit**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
ESTIMATED CONSOLIDATED COSTS											
Total bare construction cost (CAPEX)	Crore ₹	7.40	10.65	17.46	19.51	25.98	29.20	32.33	38.56	41.89	49.79
Levelized cost based on energy requirement, operation and maintenance for 25 years of life of STP	Crore ₹	7.03	9.39	19.39	17.94	27.42	28.99	30.28	37.22	38.59	48.49
Overall cost inclusive of CAPEX & OPEX	Crore ₹	14.42	20.05	36.84	37.45	53.39	58.18	62.61	75.78	80.49	98.29
COST OF LAND											
Cost of land	Crore ₹	3.52	6.24	9.80	12.25	14.92	17.54	20.14	22.70	25.30	27.91
OVERALL COST											
Overall cost inclusive of CAPEX & OPEX	Crore ₹	17.94	26.29	46.65	49.70	68.31	75.72	82.74	98.48	105.78	126.19
Overall cost inclusive of CAPEX & OPEX	Million $	2.24	3.29	5.83	6.21	8.54	9.47	10.34	12.31	13.22	15.77

End of Table A2

REGRESSION ANALYSIS AND DETERMINATION OF MAPE – MEDIUM GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		5	10	15	20	25	30	35	40	45	50
Description	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
Predicted value (as per exponential cost function)	Crore ₹	24.66	30.06	36.64	44.66	54.44	66.36	80.89	98.60	120.19	146.51
Value of R^2		0.916									
Absolute percentage error	%	37.42	14.33	21.46	10.13	20.31	12.36	2.24	0.13	13.62	16.10
MAPE	%	14.81									
Predicted value (as per linear cost function)	Crore ₹	18.06	29.55	41.05	52.54	64.03	75.53	87.02	98.51	110.01	121.50
Value of R^2		0.9885									
Absolute percentage error	%	0.65	12.41	12.01	5.72	6.26	0.26	5.17	0.04	3.99	3.72
MAPE	%	5.02									
Predicted value (as per logarithmic cost function)	Crore ₹	1.45	32.81	51.15	64.16	74.26	82.51	89.48	95.52	100.85	105.62
Value of R^2		0.8977									
Absolute percentage error	%	91.93	24.79	9.65	29.11	8.71	8.96	8.14	3.00	4.66	16.31
MAPE	%	20.53									
REGRESSION ANALYSIS AND DETERMINATION OF MAPE – MEDIUM GROUP											
BOD REMOVAL											
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		5	10	15	20	25	30	35	40	45	50
Description	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
Predicted value (as per polynomial cost function)	Crore ₹	18.53	29.71	40.97	52.31	63.73	75.23	86.81	98.47	110.21	122.03
Value of R^2		0.9886									
Absolute percentage error	%	3.29	13.02	12.16	5.26	6.70	0.65	4.91	0.01	4.18	3.30
MAPE	%	5.35									
Predicted value (as per power cost function)	Crore ₹	16.68	30.04	42.38	54.09	65.37	76.30	86.97	97.40	107.64	117.70
Value of R^2		0.9861									
Absolute percentage error	%	7.02	14.27	9.16	8.84	4.31	0.77	5.10	1.09	1.75	6.73
MAPE	%	5.90									

Table A3. Summary of results derived for large group of WWTSs with SBR technology

DESIGN SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – LARGE GROUP												
BOD REMOVAL												
		Capacity in mld	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**
		50	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
Design parameter	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
Influent flow rate	m^3/d	57800.0	69360.0	80920.0	92480.0	104040.0	115600.0	127160.0	138720.0	150280.0	161840.0	173400.0
Average BOD load	kg/d	16364.00	19636.80	22909.60	26182.40	29455.20	32728.00	36000.80	39273.60	42546.40	45819.20	49092.00
Number of reaction basins	number	13	16	18	21	23	26	29	31	34	36	39
Fill time	h	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Reaction time	h	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Design time selected for aeration	h	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Settlement time	h	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Decantation time	h	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Total cycle time	h	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Solids residence time – design value	d	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10	16.10
Total volume of each reaction basin	m^3	4446.15	4335.00	4495.56	4403.81	4523.48	4446.15	4384.83	4474.84	4420.00	4495.56	4446.15
Fill volume per cycle per reaction basin	m^3	1111.54	1083.75	1123.89	1100.95	1130.87	1111.54	1096.21	1118.71	1105.00	1123.89	1111.54
Selected value for (fill volume/ total volume of reaction basin)	ratio	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Decant depth	m	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Total liquid depth when full	m	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07
Mixed liquor suspended solids (XMLSS)	g.m^3	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00

DESIGN SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – LARGE GROUP												
BOD REMOVAL												
		Capacity in mld	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**
		50	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
Design parameter	**Unit**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
Mixed liquor volatile suspended solids (X_{MLVSS})	g.m^3	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64	1690.64
F/M	(g BOD/d)/g VSS	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Volumetric BOD loading	(kg BOD/d)/ m^3	3.68	4.53	5.10	5.95	6.51	7.36	8.21	8.78	9.63	10.19	11.04
Decant pumping rate	m^3/min	37.05	36.13	37.46	36.70	37.70	37.05	36.54	37.29	36.83	37.46	37.05
Total TSS purged per day	kg MLSS/d	14358.59	17230.31	20102.02	22973.74	25845.46	28717.18	31588.89	34460.61	37332.33	40204.05	43075.76
Observed yield based on VSS	g VSS/g BOD	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37

Continued Table A3

Observed yield based on TSS	g TSS/g BOD	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Oxygen demand per reaction basin	kg oxygen/d	1432.68	1396.86	1448.60	1419.04	1457.60	1432.68	1412.92	1441.92	1424.25	1448.60	1432.68
Total aeration time per day per reaction basin	h	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Average oxygen transfer rate per reaction basin	kg oxygen/h	179.08	174.61	181.07	177.38	182.20	179.08	176.61	180.24	178.03	181.07	179.08
Concentration of BOD in effluent	g/m^3	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66
Concentration of TSS in effluent	g/m^3	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
EQUIPMENT SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – LARGE GROUP												
BOD REMOVAL												
		Capacity in mld	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**
		50	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
Description	**Unit**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
Number of batteries		1	1	1	1	1	1	1	1	1	1	1
REACTION BASINS & ACCESSORIES												
Number of reaction basins		13	16	18	21	23	26	29	31	34	36	39
Length of each reaction basin	m	119.41	116.42	120.74	118.27	121.49	119.41	117.76	120.18	118.71	120.74	119.41
Width of each reaction basin	m	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14	9.14
Depth of each reaction basin	m	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Number of swing arm headers of each reaction basin		116	135	140	160	188	208	228	256	276	280	300
REACTOR BASIN WASTE TRANSFER PUMPS AND PUMP-HOUSE												
Total number of pumps required		2	2	2	2	2	2	2	2	2	2	2
Capacity of each pump	m^3/h	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Area required for pump-house	m^2	62.00	62.00	62.00	63.00	63.00	64.00	64.00	64.00	65.00	65.00	65.00
BLOWERS AND BLOWER BUILDING												
Total number of blowers required		5	3	3	4	4	4	5	5	5	5	5
Capacity of each blower	scfm	6921.00	16194.00	16793.00	12795.00	15020.00	16609.00	13650.00	15323.00	16511.00	16793.00	17993.00
Area required for blower building	m^2	164.00	170.00	172.00	178.00	185.00	190.00	195.00	200.00	204.00	205.00	209.00
ESTIMATED COST SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – LARGE GROUP												
BOD REMOVAL												
		Capacity in mld	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**
		50	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
Description	**Unit**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
REACTION BASINS & ACCESSORIES												
Total bare construction cost (CAPEX)	Crore ₹	38.02	47.95	55.28	66.67	79.14	92.42	106.64	121.91	138.03	148.05	165.55

Continued Table A3

Levelized cost based on energy requirement, operation and maintenance for 25 years of life of reaction basins and accessories (OPEX)	Crore ₹	47.82	56.01	58.61	67.03	78.28	86.79	95.39	106.86	115.56	118.17	127.03
Overall cost inclusive of CAPEX & OPEX	Crore ₹	85.84	103.96	113.89	133.70	157.42	179.22	202.03	228.77	253.59	266.22	292.59
REACTOR BASIN WASTE TRANSFER PUMPS AND PUMP-HOUSE												
Total bare construction cost (CAPEX)	Crore ₹	0.67	0.67	0.67	0.67	0.68	0.68	0.68	0.69	0.69	0.69	0.70
Levelized cost based on energy requirement, operation and maintenance for 25 years of life of pumps and pump-house (OPEX)	Crore ₹	0.68	0.75	0.77	0.85	0.96	1.04	1.12	1.22	1.30	1.32	1.40
Overall cost inclusive of CAPEX & OPEX	Crore ₹	1.34	1.42	1.44	1.53	1.64	1.72	1.80	1.91	1.99	2.01	2.09
BLOWERS AND BLOWER BUILDING												
Total bare construction cost	Crore ₹	11.11	13.25	13.51	15.18	16.60	17.57	19.39	20.70	21.59	21.80	22.66
ESTIMATED COST SUMMARY FOR SEQUENTIAL BATCH REACTOR BASED SYSTEM – LARGE GROUP												
BOD REMOVAL												
		Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld	Capacity in mld
		50	60	70	80	90	100	110	120	130	140	150
Description	Unit	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
ESTIMATED CONSOLIDATED COSTS												
Total bare construction cost (CAPEX)	Crore ₹	49.79	61.86	69.47	82.52	96.42	110.67	126.72	143.30	160.31	170.54	188.91
Levelized cost based on energy requirement, operation and maintenance for 25 years of life of STP	Crore ₹	48.49	56.76	59.38	67.89	79.24	87.83	96.51	108.08	116.86	119.49	128.43
Overall cost inclusive of CAPEX & OPEX	Crore ₹	98.29	118.63	128.85	150.41	175.66	198.50	223.23	251.38	277.18	290.03	317.34
COST OF LAND												
Cost of land	Crore ₹	27.91	33.11	38.29	43.53	48.73	54.01	59.30	64.53	69.86	75.10	80.47
OVERALL COST												
Overall cost inclusive of CAPEX, OPEX & Land	Crore ₹	126.19	151.73	167.14	193.94	224.39	252.51	282.53	315.91	347.04	365.13	397.81
Overall cost inclusive of CAPEX, OPEX & Land	Million $	15.77	18.97	20.89	24.24	28.05	31.56	35.32	39.49	43.38	45.64	49.73

End of Table A3

REGRESSION ANALYSIS AND DETERMINATION OF MAPE – LARGE GROUP												
BOD REMOVAL												
		Capacity in mld	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**
		50	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
Description	**Unit**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
Predicted value (as per exponential cost function)	Crore ₹	135.51	152.03	170.56	191.34	214.66	240.82	270.17	303.10	340.04	381.48	427.98
Value of R^2		0.9856										
Absolute percentage error	%	7.38	0.19	2.05	1.34	4.34	4.63	4.37	4.05	2.02	4.48	7.58
MAPE	%	3.86										
Predicted value (as per linear cost function)	Crore ₹	117.97	145.73	173.48	201.24	229.00	256.76	284.52	312.28	340.04	367.80	395.56
Value of R^2		0.9963										
Absolute percentage error	%	6.52	3.96	3.80	3.77	2.05	1.68	0.70	1.15	2.02	0.73	0.57
MAPE	%	2.45										
Predicted value (as per logarithmic cost function)	Crore ₹	95.80	141.79	180.68	214.37	244.08	270.66	294.71	316.66	336.85	355.55	372.95
Value of R^2		0.9612										
Absolute percentage error	%	24.09	6.55	8.10	10.53	8.77	7.19	4.31	0.24	2.94	2.62	6.25
MAPE	%	7.42										

REGRESSION ANALYSIS AND DETERMINATION OF MAPE – LARGE GROUP												
BOD REMOVAL												
		Capacity in mld	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**	**Capacity in mld**
		50	60	70	80	90	100	110	120	130	140	150
Description	Unit	Value		Value	Value	Value	Value	Value	Value	Value	Value	Value
Predicted value (as per polynomial cost function)	Crore ₹	123.21	147.81	173.12	199.12	225.82	253.22	281.32	310.13	339.63	369.83	400.73
Value of R^2		0.9975										
Absolute percentage error	%	2.36	2.58	3.58	2.67	0.64	0.28	0.43	1.83	2.14	1.29	0.73
MAPE	%	1.68										
Predicted value (as per power cost function)	Crore ₹	121.76	147.97	174.50	201.29	228.31	255.55	282.97	310.57	338.34	366.25	394.29
Value of R^2		0.9955										
Absolute percentage error	%	3.52	2.48	4.40	3.79	1.75	1.20	0.16	1.69	2.51	0.31	0.88
MAPE	%	2.06										