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An evaluation of operation and maintenance costs of wastewater treatment plants: Gebze wastewater treatment plant sample

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ABSTRACT

Gebze wastewater treatment plant (GWWTP) is one of the biggest wastewater treatment projects of Kocaeli Metropolitan Municipality, a leading industrial zone in Turkey, and it has been built to collect and treat domestic wastewater coming from a population of 670,000 living in Çayırova, Şekerpınar, Eskihisar, Darıca and Gebze settlements in city of Kocaeli. GWWTP has been designed to have a dry-air flow rate of 120,000 m^3/d and a wet-air flow rate of 144,000 m^3/d. The system is made up of pre-treatment, biological removal of phosphorus, denitrification through extended aeration, nitrification and final clarifier stages. In the plant, removal of many contaminants has been aimed, mainly that of chemical oxygen demand (COD), biological oxygen demand (BOD_5), suspended solids (SS), nitrogen and phosphorus. Approximate removal efficiency of COD, BOD_5, and SS are determined to be 96%, 93%, 95%, respectively. As the treatment of the wastewater has been succeeded with the treatment plant, flow of wastewater into the rivers in the region has been prevented, as well. The total annual cost is 16,900,000 TL (Turkish Liras). Unit wastewater consumption cost is 0.39 TL/m^3. Thanks to these costs, the water pollution is avoided by the treatment of wastewaters. In accord with relevant national legislation and the standards declared in UN directives, treatment of the wastewater produced in the Gebze district is provided in order not to cause any harm neither on the environment nor on the public health. Decreases in costs can be attained by the convenient operation of the plant.

Keywords: Wastewater treatment plant; Operation cost; Biological treatment; Evaluation

1. Introduction

Within the urban water cycle, special attention has been paid to the efficiency assessment of wastewater treatment plants (WWTPs). In particular, assessing the efficiency of WWTPs allows their performance to be compared and thus best practices can be identified. In this context, Hernandez-Sancho et al. [1], Sala-Garrido et al. [2], Molinos-Senante et al. [3], and Guerrini et al. [4], among others, have assessed the so-called technoeconomic efficiency of WWTPs. In doing so, they have considered that the operation and maintenance (O&M) costs of WWTPs are their inputs, while the pollutants removed from the wastewater are their outputs.

There are many alternative systems currently being practiced for the treatment of domestic wastewater. The number of those alternatives is fewer in developed countries due to the strict limitation regarding the desired quality of the treated effluent. In developing countries, however, where the economy, governments and policies change continually, the criteria for discharge vary on a wide scale ranging from strict to flexible. Besides, the cost components and operational requirements of the treatment plant are important in developed countries, while they serve as a means to decide on the type of the treatment plant in developing countries [5].

Utilities in some parts of the world, namely in developing countries, where water supply and sanitation services are extremely cheap, have been expending more than what

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they have been raking in as income, and struggling to maintain their service levels [6].

Our country entered a rapid development process in recent years, local government has funded most external sources and the planning of municipal wastewater treatment plants and so the construction has got speed. Today, wastewater treatment is applied to a great number of existing systems. More active sludge for the treatment of municipal wastewater stabilization ponds, trickling filters and biological systems, such as anaerobic treatment,are being widely used.

The planning of wastewater treatment plants in our country, namely, wastewater quantity and quality of these changes, climatic conditions, the extent and applicability of the selected treatment systems, mechanical, electrical and construction cost assessment, should be addressed in a broader framework.

Domestic wastewater treatment systems are generally designed to eliminate carbonaceous organic matter. However; because of increasing eutrophication and pollution in water receiving environment, strict discharge limits have been used in wastewater discharging especially for sensitive areas. Especially nitrogen and phosphorus parameters should primarily be controlled. In this case, additional cost and optimization treatment outputs are necessary for nitrogen and phosphorus treatment in treatment systems which already exist and will be established in many countries.

Operating costs and operating expenses will be made after the start of plant operation It includes amortization. Here are the items including operation costs in advanced domestic wastewater treatment which is being performed; energy costs: electricity, natural gas etc., chemical costs: chemicals used in P removal and those for sludge thickening in sludge dewatering polymer-lime, disposal costs: disposal of sludge and solid waste etc., repair-maintenance costs, staff costs, management costs: phone, insurance, mail etc.

Energy requirements: aeration related to the wastewater is determined by organic matter and nitrogen load. The amount of chemicals needed depends on the amount of generated sludge and the phosphorus load. Maintenance and repair costs are not installed and they only relate to the system's capacity. Primarily the system is affected by the organic material.

This study examined Gebze wastewater treatment plant (GWWTP) and the annual operating and maintenance costs and the total cost was found to be 16,900,000 TL per year. This annual O&M cost of GWWTP consists of 4,000,000 TL for personnel services, 11,000,000 TL for removal and transportation of sludge services,1,500,000 TL plant maintenance services, 250,000 TL for energy services, 100,000 TL for laboratory services, and 50,000 TL for measurement services. The highest cost in the plant is for removal and transportation of sludge services. According to, calculations the unit cost of wastewater consumption price has been 0.39 TL/m^3. Thanks to these costs, the water pollution is avoided by the treatment of wastewaters.

2. Materials and methods

2.1. General description of GWWTP

GWWTP is one of the biggest wastewater treatment projects of Kocaeli Metropolitan Municipality, which is a leading industrial zone in Turkey, and it has been built to collect and treat domestic wastewater coming from a population of 670,000 living in Çayırova, Şekerpınar, Eskihisar, Darıca and Gebze settlements in city of Kocaeli. GWWTP has been designed to have a dry-air flow rate of 120,000 m^3/d and a wet-air flow rate of 144,000 m^3/d. The initial investment cost of the GWWTP project is 67,329,414.15 TL. Fig. 1 shows the general layout of GWWTP.

Pre-anoxic zone denitrification process has been chosen in plant process for nitrogen removal. Active sludge reactor has been designed in the form of oxidation pools with piping allowing 3-stage and 5-stage pardenpho processes.

The system is made up of pre-treatment, biological removal of phosphorus, denitrification through extended aeration, nitrification and final clarifier. In the plant, removal of many contaminants has been aimed, mainly that of COD, BOD_5, SS, nitrogen and phosphorus. Table 1 shows the design and the available operation values in the plant.

Approximate removal efficiency of COD, BOD_5, SS, Total N and Total P are determined to be 96%, 93%, 95%, 88% and 70% respectively (Table 2).

The plant is an advanced biological treatment plant. The process is for the removal of nitrogen and carbon. The plant is subject to the Water Pollution and Control Regulation, Urban Wastewater Treatment Regulation and wastewater discharge values are under the values stated in these regulations. Thus, it is effective.

These processes are done around the clock over both influent and effluent wastewater samples taken and analyzed. Efficiency of the process are checked continuously. Constantly all equipment is checked and they are maintained to work for 24 h. Necessary oxygen level is maintained. For an efficient operation, sludge drawing is regularly done.

2.2. Units of treatment plant

The plant consists of the following main units (Table 3).

3. Results

3.1. O&M costs in wastewater treatment plants

The daily and annual fees of consumed chemicals, electricity, labor, maintenance, and repair, etc. should be stated in operating costs. The operational costs are all costs incurred to maintain and operate the waste water treatment plant and include items such as: Personnel, maintenance costs, operational costs, chemicals, utilities, lab supplies, office supplies etc., aeration costs (electricity), and sludge disposal costs.

There are many factors affecting operation costs, accordingly operation costs may differ widely: Size and load of the plant, topography and geographical situation of the site (e.g. effecting pumping energy costs), characteristics of wastewater and the discharge norm, technologies and the selected treatment process, type of sludge treatment and way of disposal, energy supply and energy recycling, degree of automation, measurement and process control, organization of the plant and its management [7].

Annual O&M costs of the plant are given in Table 4. Fig. 2 shows the composition of operation costs for a selected wastewater treatment plant of a population of 670,000. It can be noticed, that the cost for personnel, main-

Fig. 1. General layout of Gebze wastewater treatment plant (GWWTP).

Table 1
Design and available operation values in the plant

Design values		Available operation values
Parameters	Raw water values	(Average raw water values)
BOD_5	≤250 mg/lt	298.78 mg/lt
Total N	≤50 mg/lt	46.10 mg/lt
Total P	≤10 mg/lt	6.05 mg/lt
Suspended solids	≤300 mg/lt	321.41 mg/lt
Flow rate (dry weather)	120,000 m^3/d	
Flow rate (maximum)	144,000 m^3/d	
Flow rate		66,702 m^3/d
COD		651.50 mg/lt

tenance, energy and sludge disposal are decisive categories as these account for most of the operation costs.

As can be seen in Fig. 2, the most important cost item is the removal and transportation of sludge service, representing 65% of the total cost. Personnel service is the next in importance, representing 24% of the total cost. Plant maintenance service costs contribute another 9%. All the other cost items represent a percentage equal to or lower than 1%.

Tsagarakis et al. [8], energy accounted for 36% of the O&M expenses in activated sludge WWTPs in Greece. While that was for a south European country, Balmer [9], in a study of five Nordic WWTPs concluded that 25% of the annual O&M expenses could be attributed to energy consumption. Biehl and Inman [10] categorized the O&M expenses in a typical water treatment plant in 2008 as salaries 35%, energy 34%, chemicals 16%, other materials 13% and maintenance 15%.

Table 2
The removal efficiencies and influent–effluent concentrations (December 2013 monthly average values)

Parameters	Influent (mg/lt)	Effluent (mg/lt)	Removal efficiency (%)
BOD_5	266.1	8.2	97
COD	563.4	42.2	93
SS	284.6	19.5	93
TN	51.8	2.6	94
TP	2.9	0.5	83

Maintenance costs include the following: repairs on mechanical, electrical, electronic and civil parts and minor or major replacements like small or large parts for pumps, blowers or motors. They include internal personnel costs, material expenses and external services. Quantities of spare parts kept in stock and purchasing deals also influence the total maintenance costs.

Maintenance is an important activity that should be performed in any type of facility, thus it is necessary for proper functioning and prevents damages whose repairing can be very expensive. Even low-tech options demand maintenance activities. Maintenance should be considered in a regular time basis (semestral, annual) into the costing and budget of the project.

The ability to effectively operate and maintain a wastewater treatment system depends mainly on site conditions, proper design (including selection of appropriate materials and equipment), construction and inspection, testing and acceptance, and system start-up [11].

Table 3
The plant main units and capacities

Main units	Capacities
Inlet pumping station	Submersible pumps, 5 pieces, 1,500 m^3/h, 90 kW
Coarse screen	Mechanical-cleaning, it was designed as 4 pieces
Fine screen	Mechanical-cleaning, it was designed as 4 pieces
Aerated grit and grease chamber	Sand pumps, 4 + 1 pieces, 45 m^3/h, 2 kW
	Sand separators, 2 pieces, 90 m^3/h, 2.2 kW
Aerated grit chamber blower building	Blowers, 4 + 1 pieces, 544 m^3/h, 400 mbar, 11 kW
Anaerobic tank	Submersible mixers, 6 pieces, 5.5 kW
Aeration tank	8 oval oxidation (aeration) tanks (The depth of aeration tank is 5.70 m, width 26.00 m, length 130.00 m and total tank volume 178,338 m^3)
	Submersible mixers, 6 pieces, 5.5 kW
	Submersible mixers, 24 pieces, 7.5 kW
	Internal recirculation pumps, 8 pieces, 2,500 m^3/h, 11 kW
	Diffusers, 15,360 pieces, 9″
Blower building	6 + 2 pieces, 11,000 m^3/h, 700 mbar, 315 kW
$FeCl_3$ dosing unit	Dosing pumps, 2 + 2 pieces, 50 lt/h, 0.18 kW
Final sedimentation tank	8 units
	Rotary bridging scrapers, 8 pieces, 1.5 kW
Return sludge pumping station	Return sludge pumps, 6 + 2 pieces, 750 m^3/h, 45 kW
Excess sludge tank	Blowers, 1 + 1 pieces, 320 m^3/h, 400 mbar, 7.5 kw
Sludge dewatering unit	Decanter building;
	Macerators, 5 pieces, 90 m^3/h
	Decanter feeding pumps, 4 + 1 pieces, 72 m^3/h, 11 kW
	P.electrolyte preparation unit, 1 + 1 pieces, 7.5 m^3/h, 1.5 kW
	P.electrolyte dosing monopumps, 4 + 1 pieces, 1,000 l/h, 0.75 kW
	Decanters, 5 pieces, 67 m^3/h
	Screw conveyor, 1 piece, 1.5 kW
	Belt conveyor, 1 piece, 1.1 kW
	Drainage pump, 1 piece, 10 m^3/h, 0.75 kW
Transformer and generator building	Generators, 2 pieces, 2,200 kVA

Table 4
Annual O&M costs of the plant

O&M items	Costs (TL/y)
Personnel services	4,000,000
Removal and transportation of sludge services	11,000,000
Plant maintenance services	1,500,000
Energy services	250,000
Laboratory services	100,000
Measurement services	50,000
Total	16,900,000

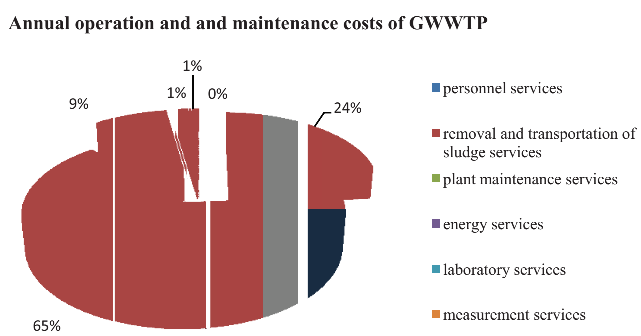

Fig. 2. Annual operation and maintenance costs of GWWTP.

3.2. Calculations by the data obtained from the plant

Considering that the monthly average flow rate and energy consumption rates of the plant, spent energy quantity for each 1 m^3 flow rate is found for the whole plant. Those values; $Q_{average}$: 2,020,723 m^3/mon; for the total of whole plant: 0.41 kWh/m^3.

If the equivalent population and the flow rate are taken into consideration, monthly used water quantity per person is calculated as $Q_{average}$/equivalent population = 2,020,723 m^3/mon/670,000 person = 3.01600 m^3 = 3,016 L/P-mon.

If the average energy amount used and the equivalent population used in design calculations are considered, energy quantity used per person can be found. Monthly average energy quantity spent on the facility is found out by Average Energy Quantity/Equivalent Population = 819,754 kWh/mon / 670,000 people = 1.223 kWh/person, and it is found out to be 1,223 W/person-mon.

GWWTP is a facility working on an activated sludge system. And high energy-working costs are known for activated sludge systems. But the fact that this system can overcome a big flowrate is also seen suitable for GWWTP.

Because of the evaluation of the data obtained from the facility, monthly average value of an overall treatment expenses and the efficiency has been found to be 92% in December 2013.Likewise, through the energy consumption and the usage of the total influent flowrate of the facility has been calculated as 0.41 kWh for 1 m^3 wastewater.

Water consumption per capita has been found to be 3,016 L·N/mon through equivalent population and average in flowrate. Monthly energy spent in the wastewater treatment facility by per person has been found to be 1,223 W using the total energy consumed in the facility and the equivalent population values. Table 5 shows GWWTP 2013-2014 year (July 2013–June 2014) values.

Total treated wastewater quantity at GWWTP in 2013–2014 (from July 2013 to June 2014) has been given in Fig. 3, while the electricity consumption quantity per person has been given in Fig. 4.

Monthly average flow rate (m^3/d), dissolved oxygen (mg/l), daily sludgeamount (kg/d), sludge inlet and outlet (DS%), and transportation distance (km) values were given in Table 6.

There are aerobic, anaerobic and anoxic processes in GWWTP. Organic carbon removal value and oxygen value must be kept between 0.6 and 1 mg/l. Oxygen measurement is made by probes.

Oxygen values are directly linked with flow rate and pollution values COD and BOD. COD entrance values and flow rate measuremnets are done in the system. However, there isn't an automation scenario related with these two parameters and oxygen. There is only an adjustment range for oxygen. Oxygen values are kept between 1 mg/l level.

Oxygen is a fundamental component of reactions providing energy in the metabolic functions body of multiplying biomass in the active sludge operated in aeorbic conditions and it is used as the last electron receiver in these reactions. One basic event in active sludge systems is the aeration. Through aeration diluted-oxygen is continuously supplied to the reaction environment. When the oxygen is indeficient, it is possible for diluted-oxygen concentration to decrease and even to finish. In this case, the whole treatment system fails. Thus, true decisions should be given for the oxygen amount needed for the multiplication environment in active sludge.

Monthly average flow rate (m^3/d), monthly average consumed energy (kWh/d), and monthly averageconsumed energy (kWh) for blower and sludge dewatering unit were given in Table 7.

After the anaylses done in biological sludge water samples, it has been determined that calorific value was high (3267 kcal/kg), organic and inorganic contents were harmless and ecotoxicologically not toxic.

Sludge is sent to cement factory as a solid fuel after it has been solidified in a rate of 21%. The construction of a

Table 5
GWWTP 2013–2014 year (July 2013–June 2014) values

Months	Total treated wastewater (m^3/mon)	Electricity consumption of the plant (kWh/mon)	Wastewater electricity consumption per m^3 (kWh/m^3)
July	2,094,500	903,953	0.43
August	2,042,500	834,898	0.41
September	1,907,500	789,239	0.46
October	2,191,537	874,948	0.40
November	2,085,563	888,397	0.43
December	2,192,532	849,150	0.39
January	2,112,189	893,350	0.42
February	1,678,269	687,814	0.41
March	2,135,480	852,892	0.40
April	1,813,849	741,997	0.42
May	2,030,958	775,049	0.40
June	1,963,800	745,366	0.40
Average	2,020,723	819,754	0.41

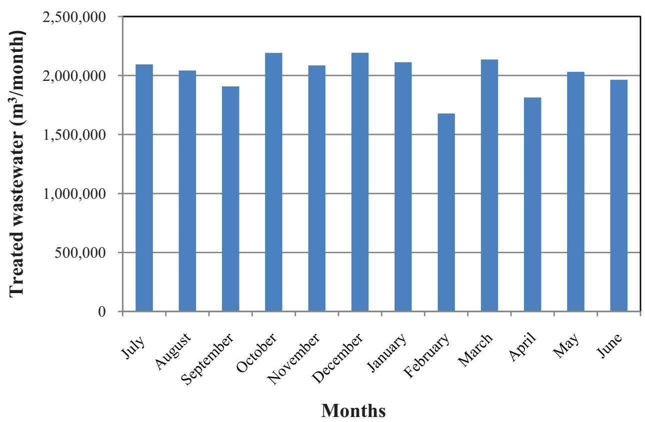

Fig. 3. GWWTP 2013–2014 year (July 2013–June 2014) total treated wastewater (m^3/mon).

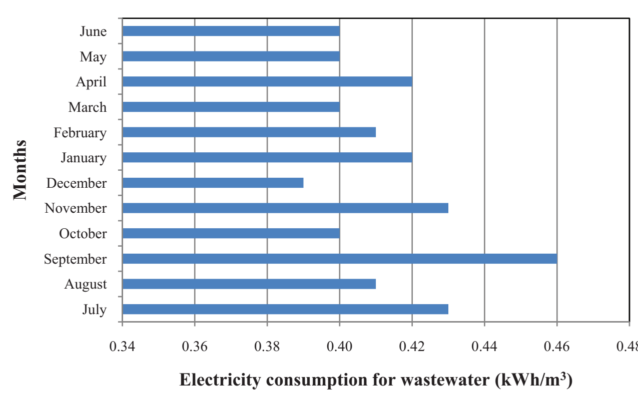

Fig. 4. GWWTP 2013–2014 year (July 2013–June 2014) for m^3 wastewater electricity consumption.

Table 6
Monthly average flow rate (m^3/d), dissolved oxygen (mg/l), daily sludge amount (kg/d), sludge inlet and outlet (DS%), and transportation distance (km) values

Months	Monthly average flow rate (m^3/d)	Monthly average dissolved oxygen (mg/l)	Sludge amount (kg/d)	Sludge inlet (total solid matter %)	Sludge outlet (total solid matter %)	Transportation distance (km)
July	67,565	1.62	23,941	1.14	22.75	31
August	65,887	1.23	37,652	1.18	22.61	31
September	63,583	1.14	54,333	1.14	22.48	31
October	70,695	1.23	59,984	0.96	21.48	31
November	69,519	1.53	51,138	1.01	21.95	31
December	70,727	1.55	66,535	1.07	21.95	31
January	68,135	1.3	48,631	1.08	22.16	31
February	59,938	1.16	41,150	1.16	21.85	31
March	68,886	1.05	27,421	1.17	22.08	31
April	70,644	0.93	97,855	1.19	22.24	31
May	70,826	0.76	40,562	1.14	22.5	31
June	75,329	0.79	55,192	1.19	22.73	31

Table 7
Monthly average flow rate (m^3/d), monthly average consumed energy (kWh/d), and monthly average consumed energy (kWh) for blower and sludge dewatering unit

Months	Monthly average flow rate (m^3/d)	Monthly average consumed energy (kWh/d)	Monthly average energy/water ratio (kWh/m^3)	Blower		Sludge dewatering	
				Monthly average consumed energy (kWh)	Percentage by consumed energy (%)	Monthly average consumed energy (kWh)	Percentage by consumed energy (%)
July	67,565	29,160	0.431584	17,891	61.4	4,012	13.8
August	65,887	26,932	0.408763	16,562	61.5	3,648	13.5
September	63,583	26,308	0.413756	16,876	64.1	3,156	12.0
October	70,695	28,224	0.399236	17,862	63.3	2,568	9.1
November	69,519	29,613	0.425970	18,517	62.5	3,756	12.7
December	70,727	27,392	0.387292	16,759	61.2	2,423	8.8
January	68,135	28,818	0.422954	18,420	63.9	2,895	10.0
February	59,938	24,565	0.409840	15,876	64.6	2,069	8.4
March	68,886	27,513	0.399399	16,873	61.3	3,276	11.9
April	70,644	29,700	0.420418	18,566	62.5	3,358	11.3
May	70,826	26,582	0.375314	16,304	61.3	2,879	10.8
June	75,329	26,561	0.352600	16,236	61.1	2,754	10.4

burning facility for sludges of GWWTP has been started and the sludges will be burned here.

4. Conclusion

Wastewater treatment plants are expensive to construct and to run. Thus, the best processes to minimize the construction and operation costs should be chosen by means of considering the feasibility reports of the facilities and, also the process of construction and operation. Besides, the facilities should be constructed with the most suitable mechanic equipment for the processes. GWWTP is a facility working on activated sludge system.

High energy-operation costs are known for wastewater treatment facilities operating on activated sludge systems. But this system that can overcome a big flow rate has also been seen suitable for GWWTP.

Because of the evaluation of the data obtained from the facility, monthly average value of an overall treatment expenses efficiency has been found to be 92% in December 2013.Similarly, through the energy consumption and the usage of the total influx flow rate of the facility has been calculated as 0.41 kWh for 1 m^3 wastewater. Thus, the total annual cost is 16,900,000 TL. Unit wastewater consumption cost is 0.39 TL/m^3. Thanks to these costs, the water pollution is avoided by the treatment of wastewaters.

As the treatment of the wastewater has been succeeded with the treatment plant, flow of wastewater into the rivers in the region has been prevented, as well. In accord with relevant national legislation and the standards declared in UN directives, treatment of the wastewater produced in the Gebze district is provided in order not to cause any harm neither on the environment nor on the public health. Decreases in costs can be attained by the convenient operation of the plant.

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