

Optimizing Rotating Biological Contactor Technology for Sustainable Wastewater Treatment: A Case Study from North Gaza

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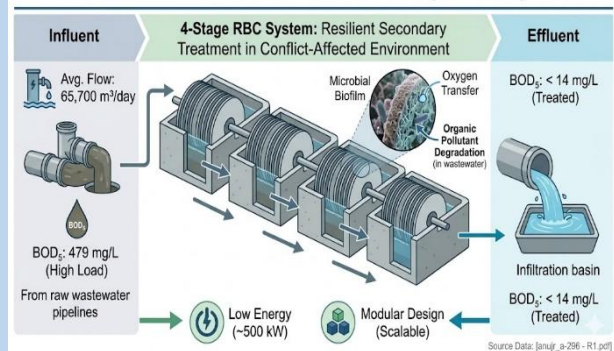
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Abstract: This study presents an integrated engineering design and performance assessment of a Rotating Biological Contactor (RBC) system for the Phase III expansion of the North Gaza Wastewater Treatment Plant (NGWWTP). The system is designed to meet stringent effluent quality standards while addressing the complex environmental and logistical constraints of the Gaza Strip. Key design parameters include a high influent BOD₅ concentration of 479 mg/L and an average daily flow of 65,700 m³/day. A four-stage RBC treatment scheme was developed and optimized for surface area loading, hydraulic retention time (HRT), and organic removal efficiency. The design achieved BOD₅ effluent concentrations below 14 mg/L, aligning with international discharge standards. In addition, secondary circular clarifiers were incorporated for solid-liquid separation, along with odor control units using biofiltration and full acoustic enclosures for noise-generating components. Compared to conventional activated sludge systems, the proposed RBC configuration offers significant advantages, including lower energy requirements (~500 kW), reduced sludge generation, and a modular setup that improves operational flexibility. Furthermore, clarifier dimensions are approximately 20% smaller, reducing capital expenditure and land use. While technically and environmentally promising, implementation remains dependent on the availability of materials, skilled personnel, and sustained financial support—challenges exacerbated by the blockade and fragile infrastructure. This research demonstrates the viability of RBC systems as resilient and sustainable solutions for wastewater treatment in conflict-affected and resource-constrained environments, providing a foundation for decentralized, low-energy wastewater infrastructure in Gaza.

Rotating Biological Contactor (RBC) wastewater treatment system for the North Gaza Wastewater Treatment Plant (NGWWTP)



Keywords: Rotating Biological Contactor (RBC), Wastewater Treatment; BOD₅ removal, Biological treatment design, Secondary clarification, Sustainable sanitation, Gaza Strip.

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INTRODUCTION

The treatment of wastewater is a critical component of sustainable development, public health protection, and environmental preservation, especially in water-scarce regions [1]. With increasing population densities, urbanization, and climate-induced water stress, the global demand for safe and cost-effective wastewater treatment solutions has grown significantly. Effective treatment technologies not only prevent the spread of waterborne diseases but also facilitate the recovery and reuse of water, nutrients, and energy, contributing directly to Sustainable Development Goal 6: Clean Water and Sanitation for All [2-3].

Biological treatment processes, particularly secondary treatment units, play a central role in removing organic pollutants and nutrients from municipal wastewater [4]. Among various biological treatment technologies, Rotating Biological Contactors (RBCs) have gained renewed attention in recent years due to their simplicity, energy efficiency, and robustness in handling variable organic loads [5]. RBCs are fixed-film reactors that employ a series of partially submerged rotating discs on which microbial biofilms develop. As the discs rotate through the wastewater and air, the biofilms are alternately exposed to organic pollutants and oxygen, facilitating aerobic degradation [6]. Compared to conventional activated sludge systems, RBCs offer several advantages: they require minimal energy input, are easy to operate and maintain, and occupy a smaller physical footprint—making them particularly attractive for low-resource and crisis-affected regions [7].

In recent decades, numerous studies have investigated the performance, optimization, and field applications of RBC systems under various environmental conditions. Abdelkader (2021) reported consistent BOD and COD removal rates exceeding 93%, even under fluctuating hydraulic loads [8]. Waqas et al. (2023) examines RBC applications in decentralized wastewater systems, highlighting their potential as sustainable solutions for rural and remote areas. The analysis compares RBCs with other treatment technologies, outlining their advantages, limitations, and contribution to sustainable environmental performance [5]. Moreover, advancements in disc materials, rotational speed control, and reactor configuration have significantly enhanced oxygen transfer efficiency and microbial stability [9]. Despite these promising developments, the literature remains limited in addressing the use of RBCs in politically unstable or severely resource-constrained settings—leaving a critical knowledge gap regarding their feasibility and adaptability in such environments.

The Gaza Strip presents one of the most complex and urgent wastewater management challenges in the world, where effective treatment is essential not only to protect the receiving environment but also to enable the safe reuse of treated wastewater for agricultural irrigation without causing environmental degradation [10]. Over the past two decades, the region has faced a combination of factors—ongoing blockade, rapid urban expansion, aging infrastructure, and repeated military conflicts—that have severely hindered the development of resilient wastewater treatment facilities [1]. Currently, Gaza experiences a widespread collapse of wastewater treatment infrastructure, exacerbated by recurring power outages and fuel shortages. Since October 2023, nearly all five municipal wastewater treatment plants have ceased operation, resulting in daily discharge of over 130,000 m³ of untreated sewage into the Mediterranean Sea [11-12]. Historic data indicate that between 50,000 and 80,000 m³/day of sewage remained untreated even before recent conflicts [13]. Consequently, Gaza's coastal

aquifer—the primary drinking water source for over 90% of the population—has deteriorated, with over 90% of groundwater unfit for human consumption due to high nitrate and salinity levels, and documented health risks including methemoglobinemia (“blue baby syndrome”) [11,14].

Decentralized wastewater treatment systems—particularly modular RBC units—offer a viable alternative in conflict-affected settings like Gaza. These systems require less energy, tolerate fluctuating loads, and operate with minimal supervision, making them suitable where centralized infrastructure has collapsed [15-16]. To date, RBC technology has not been employed in any wastewater treatment facility in the Gaza Strip, despite its potential to address many of the region's pressing constraints. The absence of studies or implementation projects involving RBCs in Gaza suggests a critical gap in the applied knowledge and design practice.

This paper addresses the lack of applied studies on Rotating Biological Contactor (RBC) systems in conflict-affected and resource-constrained settings by presenting a design-based assessment for their use as a secondary biological treatment process at the Northern Gaza Wastewater Treatment Plant (NGWWTP). The main contributions of this study are as follows: (i) it presents a comprehensive engineering design and predictive performance evaluation of a full-scale Rotating Biological Contactor (RBC) system for high-strength municipal wastewater; (ii) it demonstrates the technical feasibility of applying RBC technology under severe energy, infrastructure, and operational constraints characteristic of conflict-affected and resource-limited environments; (iii) it integrates biological treatment design with secondary clarification, energy consumption assessment, and environmental control measures (odour and noise), providing a holistic and implementation-oriented framework; and (iv) it proposes a scalable and modular treatment approach that supports decentralized wastewater management strategies in fragile and low-resource settings.

Material and Methods

A. Study Area and Data Sources

This study focuses on the Northern Gaza Wastewater Treatment Plant (NGWWTP), a key infrastructure component designed to mitigate the chronic wastewater management crisis in the Gaza Strip. Located in the northern governorate, the NGWWTP was planned in three construction phases to accommodate increasing wastewater inflows and projected population growth. Phase I was completed in 2004 with a design capacity corresponding to the year 2012. Phase II, initiated in 2011, was designed to meet the capacity requirements of 2018[17]. The final Phase III was constructed in 2017, with design projections extending to the year 2025 as illustrated in Figure 1.

The (NGWWTP), particularly Phase III, was selected as a representative and illustrative case study due to its large design capacity, high organic loading, and operation under extreme constraints related to energy availability, infrastructure damage, and limited operational control. While the plant reflects characteristics common to large municipal wastewater treatment systems in developing regions, it also represents an extreme case in terms of political instability and resource scarcity, making it a valuable testbed for assessing the applicability of resilient and low-energy treatment technologies such as RBCs.

The scope of this report is centered on Phase III, which includes an evaluation and design proposal for implementing Rotating Biological Contactors (RBCs) as the core secondary treatment technology. While the plant initially utilized

conventional biological treatment methods, the current analysis explores RBC integration as an efficient and resilient alternative suitable for the current and future operational context of the plant.

Key elements of the wastewater treatment process at NGWWTP include preliminary and primary treatment units, secondary biological treatment (proposed as RBC in this paper), final clarification, anaerobic sludge digestion, and energy recovery through biogas generation. The plant layout also incorporates effluent pumping stations, distribution systems, and infiltration basins for aquifer recharge — underscoring the site’s strategic role in both wastewater treatment and groundwater management. Data utilized in this

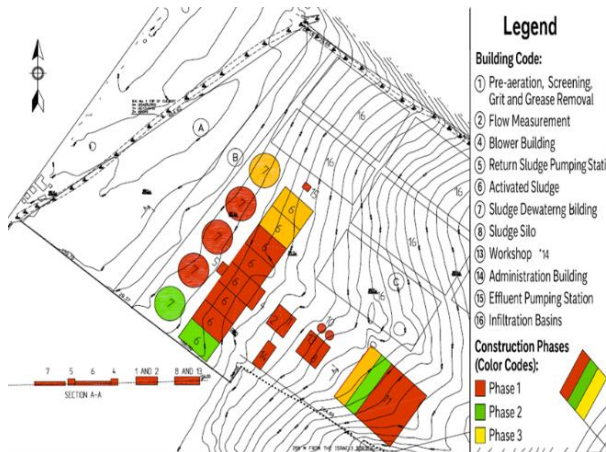


Figure (1): NGWWTP Site Layout [15]

study was primarily derived from two official technical documents: The North Gaza Emergency Sewage Treatment – Waste Water Treatment Plant: General Technical Report, and the Final Detailed Evaluation: Palestinian Water Authority – Phase III/Northern Gaza Wastewater Treatment Plant. These reports provided detailed design parameters, operational history, and projected hydraulic and organic loads essential for the proposed RBC system assessment and design [16]. The data obtained from previous technical reports served as input parameters for an independent engineering analysis and system design. The process layout is presented in Figure 2.

B. Influent Characteristics and Design Basis of Northern Gaza WWTP

The design of the Northern Gaza Wastewater Treatment Plant (NGWWTP) is based on projected organic and hydraulic loads across three development phases, extending from the initial start-up (2005) to the design horizon year 2025. Table 1 presents the detailed influent characteristics and design parameters used in sizing the treatment units. These values were derived from field measurements at Beit Lahia WWTP and extrapolated to reflect expected growth in population, water use, and sewer coverage. The data reveals a clear upward trend in influent volume and pollutant loads across the three phases. The average daily flow rises from approximately 19,670 m³/d at start-up to 65,700 m³/d by Phase III, while organic loads such as BOD₅ and COD nearly double. The per capita water consumption also increases from 87 to 120 L/pe.d, driven by improved living conditions and infrastructure expansion [17-18].

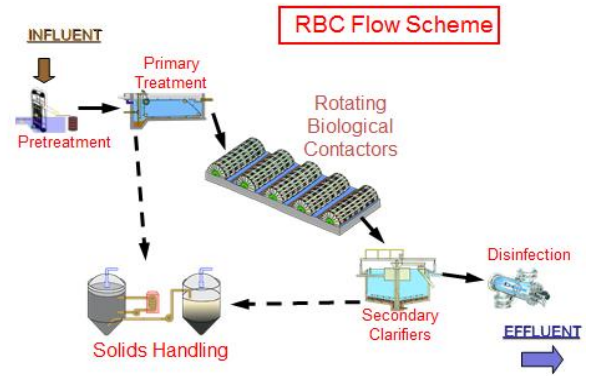


Figure (2): Plant Schematic with RBC

Table 1. Design Influent Characteristics and Load Projections for Northern Gaza WWTP (2005–2025)

Parameter	Unit	Start-Up (2005)	Phase 1 (2005 – 2012)	Phase 2 (2012– 2018)	Phase 3 (2018– 2025)
Population equivalents	pe	217,500	326,900	420,600	530,000
Industrial equivalents	pe	8,700	17,400	17,400	17,400
Total equivalents	pe	226,200	344,300	438,000	547,400
Q population	m ³ /d	18,850	33,960	47,660	63,560
Q industrial	m ³ /d	820	1,640	1,640	1,640
Q total average	m ³ /d	19,670	35,600	49,300	65,700
Q design	m ³ /d	1,100	1,975	2,725	3,600
Q peak	m ³ /h	3,820	4,750	5,550	6,480
Q population specific	L/pe.d	87	104	113	120
COD	kg/d	24,656	37,529	47,742	59,667
BOD ₅	kg/d	12,893	19,625	24,966	31,202
Total-N	kg/d	2,488	3,787	4,818	6,021
NH ₄ -N	kg/d	2,036	3,099	3,942	4,927
Total-P	kg/d	452	689	876	1,095
Suspended Solids (SS)	kg/d	13,572	20,658	26,820	32,844
COD/BOD	—	1.9	1.9	1.9	1.9
BOD/Total-N	—	5.2	5.2	5.2	5.2
COD	g/pe.d	109	109	109	109
BOD ₅	g/pe.d	57	57	57	57
Total-N	g/pe.d	11	11	11	11
NH ₄ -N	g/pe.d	9	9	9	9
Total-P	g/pe.d	2	2	2	2
Suspended Solids (SS)	g/pe.d	60	60	60	60
COD	mg/L	1,253	1,054	968	915
BOD ₅	mg/L	655	551	506	479
Total-N	mg/L	126	106	98	92
NH ₄ -N	mg/L	103	87	80	76
Total-P	mg/L	23	19	18	17
Suspended Solids (SS)	mg/L	690	580	533	504

These trends underscore the escalating burden on the treatment facility and the critical need for a scalable and energy-efficient secondary treatment solution. Table 1 summarizes the influent characteristics, including total and per capita pollution loads for parameters such as COD, BOD₅, Total Nitrogen (N), Ammonium (NH₄-N), Phosphorus (P), and Suspended Solids (SS). These loads increased markedly due to population growth, expanded service area, rising per capita water use (from 114 to 150 L/c/d), and the full coverage of the sewerage network (from 70% to 100%).

The projected influent for Phase III (target year 2025) is characterized by an average daily flow of approximately 65,700 m³/d and organic loads reaching 59,667 kg COD/d and 31,202 kg BOD₅/d. These high and variable loads further justify the need for a resilient biological treatment process, such as RBCs, which offer operational stability and reduced energy requirements. Effluent standards in the Gaza Strip are designed to meet both environmental protection and reuse objectives. For treated wastewater intended for aquifer recharge and unrestricted irrigation, the targeted effluent quality must meet the following criteria: BOD₅: 10–20 mg/L, Suspended Solids (SS): 15–20 mg/L, Total Nitrogen: 10–15 mg/L, Helminths: <1 No./L, and Faecal coliforms: <200 MPN/100 mL.

These limits are based on annual and monthly performance thresholds of 24-hour composite samples and emphasize both public health safety and aquifer protection. Additionally, the potential for clogging of infiltration basins due to high suspended solids necessitates stringent quality control. Sludge management strategies include centrifugation to 25% dry solids followed by a 100-day storage period to comply with sanitary standards. This detailed understanding of both influent dynamics and effluent targets forms the scientific basis for evaluating the suitability and sizing of an RBC-based secondary treatment process in the context of the Northern Gaza WWTP.

This study adopts a design-based and analytical engineering methodology to evaluate the feasibility and performance of a Rotating Biological Contactor (RBC) system as a secondary treatment process for the Northern Gaza Wastewater Treatment Plant (NGWWTP). The methodology consists of four main steps: (i) collection and analysis of influent wastewater characteristics and hydraulic loading data from official design and monitoring reports; (ii) application of internationally recognized RBC design guidelines and empirical models to determine key system parameters, including organic loading rates, media surface area, staging configuration, and hydraulic retention time; (iii) performance prediction of BOD₅ removal efficiency using established design equations; and (iv) evaluation of operational, energy, and environmental aspects to assess system suitability under local constraints.

The analysis relies on design-phase data obtained from official technical reports issued by the Palestinian Water Authority. Due to prolonged operational disruptions and limited access to monitoring infrastructure, long-term operational performance data were not available. Accordingly, system performance was assessed using predictive design models rather than continuous field measurements.

Preliminary and Primary Wastewater Treatment

This section provides a concise description of the existing preliminary and primary treatment units at the Northern Gaza Wastewater Treatment Plant. The objective is to establish the baseline treatment conditions and operational constraints that directly influence the design and performance requirements of the proposed RBC-based secondary treatment system. The description is therefore presented to support the methodological framework of the study rather than as a literature review.

The preliminary and primary treatment stages at the Northern Gaza Wastewater Treatment Plant (NGWWTP) are integral to the overall process train, serving as the first defense against solids, oils, and other contaminants that may disrupt subsequent biological processes. Designed to accommodate the projected hydraulic and organic loads through Phase III, these

stages collectively ensure efficient removal of coarse debris, grit, grease, and settleable solids, thereby enhancing system reliability and longevity.

Preliminary treatment at NGWWTP includes pre-aeration basins, fine screening, grit and grease removal, and flow measurement units. These units work synergistically to minimize equipment wear, prevent clogging, and control odour and corrosion, particularly in light of the long wastewater conveyance distances and high sulphate content in the influent.

Following this, the primary treatment stage utilizes rectangular sedimentation clarifiers to remove settleable organic and inorganic matter. This step not only reduces the organic loading on secondary treatment but also facilitates effective sludge handling. The compact layout of rectangular clarifiers was strategically chosen to optimize land use, particularly in relation to the adjoining infiltration basins required for effluent reuse and aquifer recharge. Together, these preliminary and primary units form a robust pretreatment system that ensures consistent operational performance while safeguarding downstream treatment processes.

A. Pre-Aeration

Due to the extended length (approximately 8,000 meters) of the pressure main connecting the New Terminal Pumping Station to the NGWWTP, wastewater experiences long retention times during night hours. Combined with elevated temperatures (20–30°C) and sulfate concentrations reaching up to 100 mg/L, this environment promotes the formation of hydrogen sulfide (H₂S), posing significant corrosion and odour risks throughout the facility. To address this, pre-aeration basins are used to oxidize the influent, thereby reducing anaerobic conditions that facilitate H₂S generation. These basins are fully covered, and excess air is directed to an odour treatment system to minimize the release of malodorous gases. Design parameters are presented in Table 2.

B. Fine screening

Fine screening is a critical mechanical step that protects pumps and downstream biological units from damage by coarse solids. The NGWWTP includes three operational fine screens and one standby unit, each designed for a maximum flow of 2,160 m³/h, totaling 6,480 m³/h to accommodate peak hourly flows in Phase III. Each screen has a bar spacing of 2 mm, which ensures effective removal of suspended solids that might clog or damage sensitive equipment. The expected volume of fine screenings is 4.4 m³/day, with a total annual volume of approximately 1,600 m³ projected during Phase I. The sizing and number of screens will be further refined in the detailed design phase. Design parameters are presented in Table 2.

C. Grit and Grease Removal

The grit and grease removal system consists of two parallel treatment lines, designed to handle the maximum hourly flow of 6,480 m³/h. Each line includes grit chambers with a combined volume of 550 m³, providing a hydraulic retention time of about 9 minutes under Phase III conditions. This design is optimized to capture sand particles ranging from 0.15 to 0.2 mm. Grease is separated in a dedicated chamber adjacent to the grit chambers, where surface scrapers transport the floated material to grease pits. The collected grease is then pumped to a combined storage tank shared with floating sludge from the primary clarifiers, before being hauled by truck to an external disposal site. The entire system is integrated with an odour control unit to minimize emissions from organic matter decomposition.

The aeration system in the grit chambers is designed for an air supply rate of 12–15 m³ per meter of tank length per hour, ensuring optimal separation performance. Estimated grit production in Phase I (2012) is around 4,900 m³/year, based on an assumed specific production rate of 15 L/pe-d, although this may vary based on actual operational data. Design parameters are presented in Table 2.

D. Flow measurement

Flow measurement is conducted using two Parshall flumes, located downstream of the grit and grease chambers. These flumes are designed to measure up to 3,240 m³/h each, matching the projected maximum hourly flow in Phase III. This arrangement ensures high measurement accuracy ($\pm 0.5\%$), which is critical for process control, system monitoring, and regulatory reporting. The dual-flume configuration also enhances redundancy and operational reliability, particularly during early operational phases (starting 2005) when flow rates are relatively low.

E. Fine screening

The primary treatment stage at the Northern Gaza Wastewater Treatment Plant (NGWWTP) was initially designed during Phase I (2012), with a hydraulic capacity equivalent to approximately 62% of the projected Phase III load. This stage plays a vital role in removing settleable solids and reducing organic matter prior to the secondary biological treatment processes. In the current layout, flow distribution is equalized across all primary clarifiers through a system of weirs, ensuring uniform hydraulic loading.

Rectangular clarifiers were selected over circular clarifiers for several strategic reasons: they require less piping infrastructure, offer a more compact arrangement, and facilitate better land utilization—particularly important for maximizing the available area for downstream infiltration basins.

Table (3) presents the key design parameters for the primary clarifiers under Phase III conditions, reflecting the upgraded capacity and performance targets. The clarifiers are specifically engineered to achieve targeted pollutant reductions under Phase III influent conditions

Table 2: Design Parameters for Pre-Aeration, Grit Removal, and Grease Removal in Phase 3

<i>Design Parameters for Pre-Aeration</i>		
Parameter	Unit	Phase 3
Number of units	Units	2
Volume, each	m ³	250
Volume, total	m ³	500
Area, each	m ²	62.5
Area, total	m ²	125
Length x Width, each	m x m	6*12.5
Depth	m	4
Retention time	Minutes	8.3
Q design	Minutes	8.3
<i>Design Parameters for Grit Removal</i>		
Parameter	Unit	Phase 3
Number of units	units	2
Volume, each	m ³	275

Volume, total	m ³	550
Area, each	m ²	80
Length x Width, each	m x m	20 x 4
Area, total	m ²	160
Depth	m	3.4
Retention time Qdesign	minutes	9
<i>Design Parameters for Grease Removal</i>		
Parameter	Unit	Phase 3
Number of units	units	2
Volume, each	m ³	250
Volume, total	m ³	500
Area, each	m ²	82.5
Length x Width	m x m	20 x 4.1
Area, total	m ²	165
Depth	m	3.0
Surface Load Qdesign	m/hour	22

Due to their relatively shallow depth and elevated surface loading rates, the resulting hydraulic retention time is lower than that of deeper tanks, leading to slightly reduced pollutant removal efficiencies. Nonetheless, performance remains within acceptable ranges for primary treatment goals.

Table (3) illustrates the assumed removal efficiencies for key pollutants, based on field sedimentation trials conducted at the Beit Lahia WWTP. Each clarifier is equipped with a sludge-thickening hopper located at the tank inlet, which facilitates the concentration of settled solids. The achieved dry solids content ranges from 3.5% to 6.0%, eliminating the need for further thickening prior to sludge treatment and stabilization processes. This configuration ensures that the primary treatment process delivers reliable solids removal and organic load reduction while optimizing space and operational efficiency within the broader NGWWTP framework. The characteristics and performance of the existing preliminary and primary treatment units define the influent conditions to the proposed RBC system and were therefore used as input parameters in the subsequent design and performance evaluation.”

Secondary wastewater treatment using RBC

This section presents detailed calculations and design parameters related to the performance of the Rotating Biological Contactor (RBC) system proposed for Phase III of the wastewater treatment plant. While the specific performance of an RBC reactor depends on the wastewater characteristics, there are several universal design parameters including rotational speed, organic and hydraulic loading rates, hydraulic retention time (HRT), media surface area, staging, temperature, dissolved oxygen (DO) concentration, recirculation, step-feeding, and medium submergence. This section presents the core contribution of the study, which consists of a design-based and analytical assessment of a Rotating Biological Contactor (RBC) system proposed as a secondary treatment unit for the Northern Gaza Wastewater Treatment Plant. The analysis is not intended as an experimental investigation, but rather as an applied engineering design supported by predictive performance evaluation using internationally accepted empirical models and design guidelines.

A. Pre-Aeration

Under typical operating conditions and low organic loading, most of the carbonaceous substrate is removed in the

Table (3): Design Parameters for Primary Clarifiers – Phase III

Design Parameters for Primary Clarifiers Phase III		
Parameter	Unit	Phase 3
Number of units	units	5
Area, each	m ²	300
Area, total	m ²	1500
Length x Width	m x m	50 x 6
Volume, each	m ³	1,050
Volume, total	m ³	5,250
Depth	m	3.5
Retention time	hours	1.5
Qdesign		
Surface Load Qdesign	m/hour	2.4
Assumed reduction in Primary Clarifiers Phase 3		
Parameter	Reduction Unit	Phase 3
COD	%	25
BOD5	%	25
Ntot	%	10
SS	%	55

first stage of the RBC. To avoid oxygen transfer limitations, the design organic loading for the first stage is limited to 30 g BOD5/m².d. For nitrification, the surface loading rate should not exceed 2.5 g BOD5/m².d to maintain effluent ammonia concentrations below 5 mg NH₄⁺/L at temperatures above 13°C.

BOD Loading Calculation:

- Influent BOD5 concentration = 479 mg/L
- Flow rate (Q) = 65,700 m³/d
- BOD5 loading = 479 mg/L × 65,700 m³/d × 1000 L/m³ × 1 g/1000 mg = 31,470,300 g/d

B. Media Surface Area

Assuming each disc has a diameter of 4 meters and a shaft length of 10 meters:

- Area of one disc (two sides): $A = 2 \times \pi \times r^2 = 2 \times 3.14 \times 2^2 = 25.13 \text{ m}^2$
- Disc spacing = 1.6 cm ⇒ 59 discs/meter
- Effective shaft length = 9.5 meters (allowing space at edges)
- Total area per shaft = 59 × 25.13 × 9.5 = 14,085 m²

To accommodate 31,470,300 g/d with a max organic loading of 30 g/m².d:

- Required media area = 31,470,300 / 30 = 1,049,010 m²

Number of shafts needed = 1,049,010 / 14,085 ≈ 74 shafts

C. RBC Staging

- Dividing the RBC into multiple stages enhances BOD and ammonia removal. Each stage functions as a

complete-mix reactor, and may have its own shaft or share a common shaft.

- Plants with ≥ 4 stages: independent shafts, flow perpendicular to shafts
- Plants with < 4 stages: one shaft, flow parallel to shaft
- Highest BOD removal occurs in the first stage, with nitrification initiating in later stages.

Design Equation: Using the US EPA empirical equation (1985) [19]:

$$S_n = [-1 + \sqrt{(1 + 0.039 * (A_s / Q) * S_{n-1})} / [0.0195 * (A_s / Q)]]$$

Where: S_n = BOD5 concentration after stage n (mg/L), A_s = media surface area of stage n (m²), and Q = flow rate (m³/d)

Stage Calculations: S₀ = 479 mg/L, Q = 65,700 m³/d

Stage 1 (74 shafts):

- A_s = 74 × 14,085 = 1,042,290 m²
- A_s/Q = 15.8 m².d/m³
- S₁ = 122.2 mg/L

Stage 2 (50 shafts):

- A_s = 732,420 m² ⇒ A_s/Q = 11.14
- S₂ = 29.25 mg/L (>14)

Stage 3 (20 shafts):

- A_s = 281,700 m² ⇒ A_s/Q = 4.28
- S₃ = 17 mg/L (>14)

Stage 4 (10 shafts):

- A_s = 140,850 m² ⇒ A_s/Q = 2.14
- S₄ = 13.3 mg/L

Four RBC stages are sufficient as illustrated in Figure 3.

Orientation: According to the Department of Environmental Protection (DEP), the system should consist of at least three

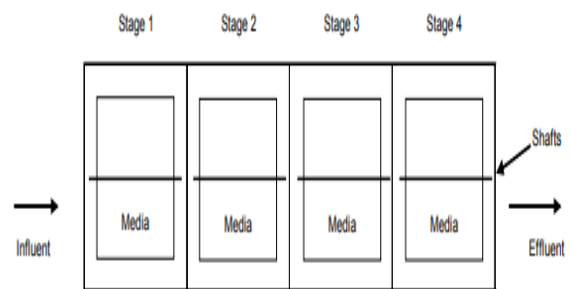


Figure (3): Schematic representation of the four-stage (RBC) system showing shaft configuration and flow direction under Phase III design conditions

cells and be operable in series and parallel configurations to provide operational flexibility as shown in Figure 4 [20].

D. Design Parameters

Hydraulic Loading Rate (HLR): Acceptable range: 0.03–0.08 m³/m².d for BOD5 + nitrification

Calculated: 65,700 m³/d ÷ 1,049,010 m² = 0.062 m³/m².d

Hydraulic Retention Time (HRT): Acceptable range: 1.5–4 hours for BOD5 + nitrification

Selected value: 2.5 hours

Tank Volume: Specific volume = 0.006 m³/m²
 For 14,085 m² shaft area: Volume = 0.006 × 14,085 = 85 m³
 Tank dimensions: L = 10.5 m, W = 4.5 m, D = 1.8 m
 Volume = 10.5 × 4.5 × 1.8 = 85 m³
 Submergence: 40% (optimal) as it illustrated in Figure 5.

E. RBC Media and Configuration

The RBC media is designed for economic viability and operational efficiency:

- Material: Polyethylene – low weight, corrosion resistance
- Disc Diameter: 4 meters
- Rotational Speed: 10 rpm
- Temperature: 20°C
- Power Requirement: Motor requirement: 3 kW per 100,000 ft² (~9290 m²) of media
- Estimated power for total system ≈ 500 kW

The RBC process consumes less than half the energy of conventional activated sludge systems, and significantly less than MBR systems. Tables 4 (A and B) Summarized the RBC Design Performance and BOD₅ Reduction in RBC System.

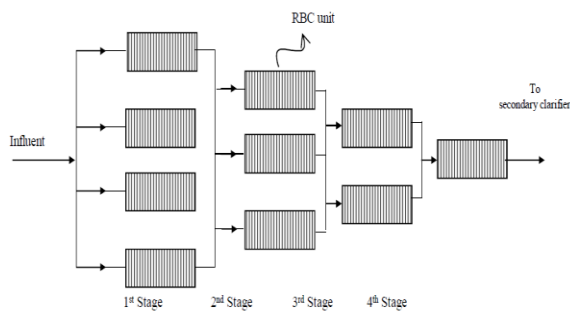


Figure (4): Parallel Orientations of Tanks

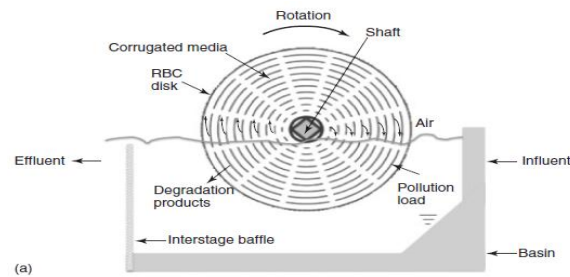


Figure (5): Schematic representation of (a) a rotating biological contactor, with approximately 40% submergence.

Secondary Clarification

Following biological treatment via the Rotating Biological Contactor (RBC) system, the treated effluent flows into the secondary clarification units. These clarifiers play a crucial role in separating the biological sludge from the treated water, thereby improving effluent quality and facilitating effective sludge management.

The clarifiers are of the circular type and are designed based on surface loading rates and tank depth to ensure sufficient settling efficiency and hydraulic capacity. Adequate design allows for proper sludge withdrawal and minimization of suspended solids in the effluent.

Table (4-A) Summary of design parameters and predicted performance of the proposed four-stage RBC system for Phase III of the Northern Gaza Wastewater Treatment Plant

Parameter	Value	Notes
Influent BOD ₅	479 mg/L	Measured design value
Effluent BOD ₅	13.3 mg/L	Achieved after 4 stages
Design Flow (Q)	65,700 m ³ /day	Daily average flow
Required Media Area	1,049,010 m ²	Based on 30 g BOD ₅ /m ² .day loading limit
Number of RBC Shafts	74	Each shaft provides ~14,085 m ² media
Organic Loading (Stage 1)	30 g BOD ₅ /m ² .day	US EPA maximum recommended
Hydraulic Loading Rate (HLR)	0.062 m ³ /m ² .day	Within optimal range
Hydraulic Retention Time (HRT)	2.5 hours	For BOD and nitrification removal
Motor Power Requirement	~500 kW	Estimated total for RBC units
Media Submergence	40%	Optimized for oxygen transfer

Table (4-B). Stage-wise BOD₅ Reduction in RBC System

Stage	Media Area (m ²)	A/Q (m ² .d/m ³)	Effluent BOD ₅ (mg/L)
1	1,042,290	15.8	122.2
2	732,420	11.14	29.25
3	281,700	4.28	17.00
4	140,850	2.14	13.3

As part of Phase I (2012), three circular secondary clarifiers were constructed. Each clarifier is equipped with a full-radius bottom scraper system and multiple sludge withdrawal points distributed across the tank base to ensure uniform sludge collection. In addition, deflection discs are installed to improve flow distribution and enhance sedimentation performance by minimizing short-circuiting [16].

A. Noise and Odour Control

A comprehensive environmental management strategy has been integrated into the plant design to mitigate noise and odour emissions—two common nuisances associated with wastewater treatment facilities.

All mechanical equipment known to produce significant noise—such as blowers, pumps, and centrifuges—is installed within purpose-built enclosures or buildings to limit noise propagation. The design ensures that:

- The maximum noise level emitted by any individual unit does not exceed 100 dB(A).
- External noise levels are maintained below 72 dB(A) due to the incorporation of acoustic insulation and soundproof building materials.

If required, additional sound attenuation systems (e.g., silencers, vibration isolators) will be installed to ensure compliance with national environmental and occupational health standards.

B. Odour Management Strategy

Odour control is achieved through a centralized system that captures and treats foul air from process units most prone to odour emissions. This system consists of two dedicated biofilter units strategically located:

- One adjacent to the pre-treatment building
- One near the sludge handling and storage area

These biofilters are designed to treat air from the following critical locations:

Pre-aeration basins – fully enclosed to contain odours

Inlet and outlet channels – sealed at key flow junctions

Fine screening chambers – enclosed for complete air control

Grit and grease removal units – partially enclosed

Screening and grit containers – hooded and connected to suction ducts

All process units within the pre-treatment area—such as debris pits, grit chambers, and mechanical screens—are either fully enclosed or provided with airtight covers. These units are directly linked to the air collection network to ensure continuous suction and ventilation.

Moreover, all conveyors for screenings and grit transport are sealed, and disposal containers are equipped with hoods connected to the suction system. The odour control strategy also accounts for primary clarifiers, where low hydraulic retention times are adopted to minimize anaerobic conditions that typically cause odour release.

Discussion

The design and performance modeling of the Rotating Biological Contactor (RBC) system proposed for the Phase III expansion of the North Gaza Wastewater Treatment Plant (NGWWTP) demonstrates the potential viability of an efficient, low-energy alternative to conventional suspended-growth systems. Based on empirical design calculations, the four-stage RBC configuration is expected to reduce influent BOD₅ concentrations from 479 mg/L to approximately 13.3 mg/L under Phase III design conditions, meeting international standards (<20 mg/L) for secondary wastewater treatment. These results are consistent with RBC performance benchmarks reported in international literature.

Although the predicted effluent BOD₅ concentration is derived from design calculations rather than experimental validation, the estimated value falls within the performance range reported for full-scale RBC systems treating high-strength municipal wastewater. Several studies have demonstrated that four-stage RBC configurations operating under similar organic loading rates and temperatures can consistently achieve effluent BOD₅ levels below 20 mg/L, supporting the plausibility of the predicted performance.

“The observed effluent BOD₅ concentration of 13.3 mg/L is consistent with, and in some cases superior to, values reported in previous full-scale RBC studies treating influent concentrations between 400 and 500 mg/L. For example, Waqas et al. (2023) and Cortez et al. (2008) reported effluent BOD₅ ranges of 15–20 mg/L under less restrictive operational conditions. Achieving comparable performance in the present study, despite severe energy limitations and operational constraints, highlights the robustness of the proposed design.

The progressive reduction in BOD₅ across the four RBC stages can be attributed to the staged decrease in organic loading and the development of a stratified biofilm structure. High substrate concentrations in the first stage promote rapid heterotrophic growth and carbon removal, while subsequent stages operate under lower organic loads, allowing for more stable biofilm activity and enhanced polishing performance. The selected surface loading rate of 30 g BOD₅/m²·d in the first stage prevented oxygen limitation, which is a common cause of performance deterioration in high-strength wastewater applications.

The total media surface area required for the proposed system was calculated at 1,049,010 m², distributed across 74 shafts, which maintained the organic loading below 30 g BOD₅/m²·d in the first stage and ensured gradual pollutant reduction across subsequent stages. The hydraulic loading rate (HLR) of 0.062 m³/m²·d and hydraulic retention time (HRT) of 2.5 hours fall well within the optimal operational range for combined BOD and ammonia removal [19]. These values align closely with operational RBC systems studied in similar climatic conditions, such as those implemented in small to medium-sized plants, where comparable HRTs and HLRs achieved BOD₅ reductions above 90% [21-22].

Moreover, the use of high-efficiency polyethylene media and optimal submergence (40%) enhances oxygen transfer and biomass retention, factors that significantly improve treatment stability and nitrification potential. The estimated energy requirement of approximately 500 kW for the full system further reinforces the advantage of RBC technology, particularly in energy-constrained environments such as Gaza. Compared to activated sludge systems, which often require higher aeration energy, the RBC setup reduces energy demands by over 50%, as also noted by Metcalf & Eddy (2014) and recent case studies in decentralized treatment systems [5]. In addition, water and wastewater infrastructure in the Gaza Strip requires minimizing electricity consumption and increasing reliance on renewable energy sources, which is consistent with the findings reported by Mizyed (2025) [23].

Several full-scale RBC systems worldwide have consistently achieved effluent BOD₅ levels between 15–20 mg/L with influent concentrations of 400–500 mg/L under ambient conditions (~20 °C). These systems generally employ three to four stages, optimized for hydraulic retention, aeration, and media surface area [15,22].

With respect to nitrogen, the proposed RBC system is primarily expected to promote nitrification rather than complete nitrogen removal. Under the selected hydraulic retention time, surface loading rates, and operating temperature (~20°C), ammonia oxidation to nitrate is expected to occur in the later stages of the RBC, as commonly reported in fixed-film aerobic systems. However, conventional RBC configurations provide

limited denitrification due to the absence of sustained anoxic conditions. As a result, while significant ammonia reduction is anticipated, total nitrogen removal is expected to be modest unless additional anoxic treatment steps or post-treatment processes are incorporated. This limitation was considered acceptable within the scope of the proposed secondary treatment objectives, which prioritize organic matter removal and ammonia stabilization over full biological nitrogen removal.

The performance of the North Gaza design is comparable, yet the proposed four-stage configuration provides an added margin for resilience and effluent quality under fluctuating influent loads and limited operational control, which is often the case in conflict-affected regions. It should be noted that the predicted performance of the proposed RBC system is based on design-phase analysis rather than operational validation. Due to the absence of pilot-scale testing and long-term monitoring data, the results represent expected performance under ideal design and operating conditions. Future work should focus on pilot implementation and post-construction monitoring to validate and refine the proposed design.

To date, RBC systems are not widely adopted in Palestine, with most treatment plants, such as those in Nablus and Hebron, relying on conventional activated sludge processes. This research contributes a novel approach by adapting RBC technology to the Gaza context, where energy scarcity, material constraints, and maintenance challenges necessitate more robust and decentralized treatment options. The modularity of the RBC system, combined with lower capital and operational costs, positions it as a sustainable alternative with high potential for replication across other under-resourced regions [24].

From a practical perspective, the results demonstrate that RBC systems can provide reliable secondary treatment with significantly lower energy demand and operational complexity compared to activated sludge systems. From a policy standpoint, the findings support the inclusion of modular RBC-based systems in wastewater management strategies for fragile and conflict-affected regions, where centralized and energy-intensive technologies are often unsustainable. Theoretically, the study reinforces the understanding that staged fixed-film systems can maintain high treatment efficiency under variable and high-strength loading conditions when appropriately designed.

Despite its promising performance characteristics, the practical implementation of this system in Gaza remains challenged by the import restrictions on construction materials and equipment, as well as limitations in technical manpower and financial support [25]. Future efforts must therefore focus on policy facilitation, local capacity building, and donor engagement to translate this technically sound solution into a working infrastructure.

Conclusion

This study presents a comprehensive engineering and environmental assessment of a Rotating Biological Contactor (RBC) system proposed for the Phase III expansion of the North Gaza Wastewater Treatment Plant (NGWWTP). The design-based analysis demonstrates the potential technical feasibility and operational advantages of RBC technology for high-load municipal wastewater treatment, particularly under the energy, infrastructure, and operational constraints of the Gaza Strip.

Using projected influent characteristics and internationally accepted empirical design models, the proposed four-stage RBC

configuration is expected to achieve effluent quality consistent with international secondary treatment standards while maintaining low energy demand and operational simplicity. The modular system layout, integrated secondary clarification, and environmental control measures further enhance system robustness and suitability for dense urban settings.

Compared to conventional activated sludge and membrane bioreactor systems, the proposed RBC configuration offers lower energy consumption, reduced sludge production, and improved scalability, making it a technically attractive option for wastewater treatment in Gaza's constrained context. Nevertheless, successful implementation remains dependent on external factors, including material availability, skilled workforce development, and long-term financial sustainability.

Overall, this study confirms that RBC technology represents a resilient, energy-efficient, and adaptable solution for wastewater treatment in conflict-affected and resource-limited regions. Future efforts should focus on policy coordination, pilot implementation, and post-construction monitoring to support the transition from design to full-scale operation.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

A.M. is the sole author of this manuscript. A.M. conceptualized the study, designed the methodology, collected and analyzed the data, interpreted the results, prepared the figures and tables, and wrote the manuscript. A.M. reviewed and approved the final version of the manuscript.

Conflict of Interest

The author declare that they have no conflict of interest.

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Ethics Approval

This study did not involve human participants, human data, animals, or animal-derived materials. Therefore, ethics approval was not required.

Consent for Publication

"The author, as the sole researcher, consents to the publication of this study. There are no copyright restrictions or specific agreements related to the publication, and it has been confirmed that all data and content can be published without any limitations.

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Not applicable.

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