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

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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 BOD_5 concentration of 479 mg/L and an average daily flow of 65,700 m^3/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 BOD_5 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.**

Keywords: Rotating Biological Contactor (RBC); Wastewater Treatment; BOD_5 removal; Biological treatment design; Secondary clarification; Sustainable sanitation; Gaza Strip.

I. 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 [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 m^3 of untreated sewage into the Mediterranean Sea [11-12]. Historic data indicate that between 50,000 and 80,000 m^3/day of sewage remained untreated even before recent conflicts [13]. Consequently, Gaza's coastal aquifer—the primary drinking water source for over 90% of

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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 aims to contribute to filling that gap by presenting a detailed design proposal for the use of RBCs as a secondary biological treatment unit at the Northern Gaza Wastewater Treatment Plant (NGWWTP). The design process incorporates best engineering practices and considers key local constraints—including land availability, power reliability, influent variability, and effluent quality targets—in order to maximize pollutant removal efficiency and ensure long-term sustainability.

II. 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.

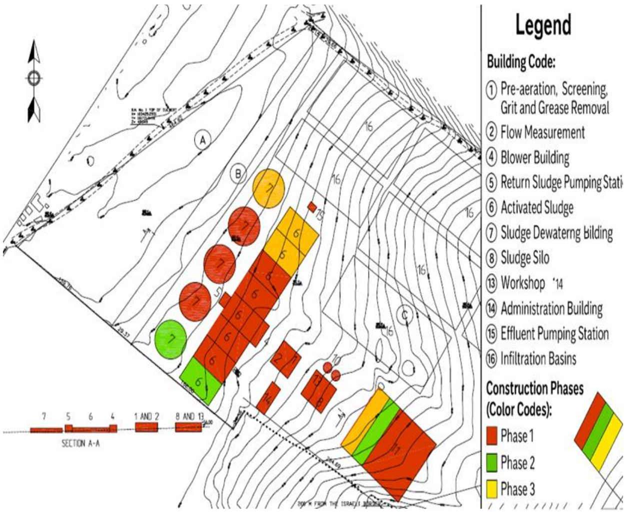

Figure (1): NGWWTP Site Layout [15]

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 study were 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 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 m^3/d at start-up to 65,700 m^3/d by Phase III, while organic loads such as BOD_5 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].

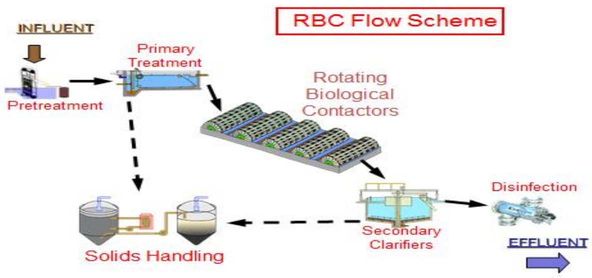

Figure (2): Plant Schematic with RBC

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, BOD_5, Total Nitrogen (N), Ammonium (NH_4-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 m^3/d and organic loads reaching 59,667 kg COD/d and 31,202 kg BOD_5/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: BOD_5: 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.

III. PRELIMINARY AND PRIMARY WASTEWATER TREATMENT

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 (H_2S), 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 H_2S 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 m^3/h, totaling 6,480 m^3/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 m^3/day, with a total annual volume of approximately 1,600 m^3 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 m^3/h. Each line includes grit chambers with a combined volume of 550 m^3, 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 m^3 per meter of tank length per hour, ensuring optimal separation performance. Estimated grit production in Phase I (2012) is around 4,900 m^3/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. *Grit and Grease Removal*

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 m^3/h each, matching the projected maximum hourly flow in Phase III. This arrangement ensures high measurement accuracy (±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

Design Parameters for Pre-Aeration		
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 × Width, each	m×m	6*12.5
Depth	m	4
Retention time	Minutes	8.3
Q design	Minutes	8.3
Design Parameters for Grit Removal		
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 × Width, each	m × m	20 × 4
Area, total	m^2	160
Depth	m	3.4
Retention time Qdesign	minutes	9
Design Parameters for Grease Removal		
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.

IV. PRELIMINARY AND PRIMARY WASTEWATER TREATMENT

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.

A. Pre-Aeration

Under typical operating conditions and low organic loading, most of the carbonaceous substrate is removed in the 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 NH_4^+/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

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	m²	300
Area, total	m²	1500
Length x Width	m x m	50 x 6
Volume, each	m³	1,050
Volume, total	m³	5,250
Depth	m	3.5
Retention time Qdesign	hours	1.5
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

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): $A = 2 \times \pi \times r^2 = 2 \times 3.14 \times 2^2 = 25.13$ m²
- 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: S_0 = 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
- S_1 = 122.2 mg/L

Stage 2 (50 shafts):

- A_s = 732,420 m² ⇒ A_s/Q = 11.14
- S_2 = 29.25 mg/L (>14)

Stage 3 (20 shafts):

- A_s = 281,700 m² ⇒ A_s/Q = 4.28
- S_3 = 17 mg/L (>14)

Stage 4 (10 shafts):

- A_s = 140,850 m² ⇒ A_s/Q = 2.14
- S_4 = 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

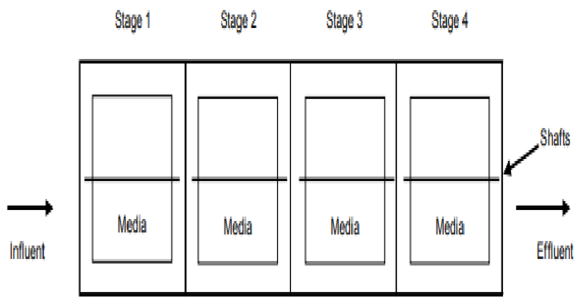

Figure (3): Four Shafts and Flow Parallel to the Shaft

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 BOD_5 Reduction in RBC System.

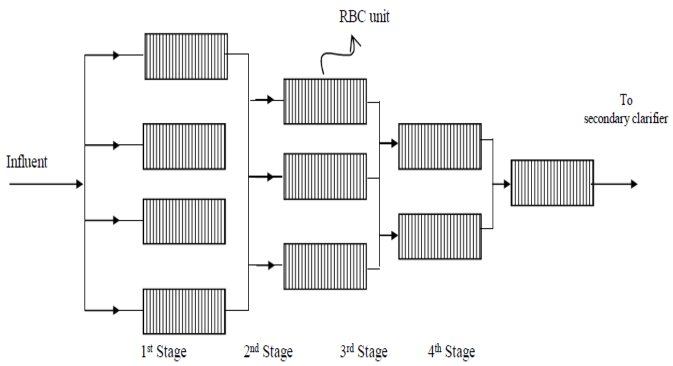

Figure (4): Parallel Orientations of Tanks

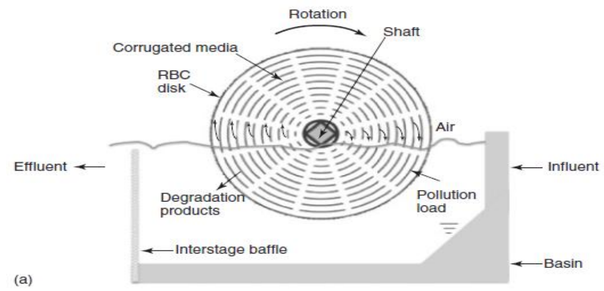

Figure (5). Schematic representation of (a) a rotating biological contactor, with approximately 40% submergence.

V. 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 RBC Design Performance – North Gaza Phase III

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 m³/day	Daily average flow
Required Media Area	1,049,010 m²	Based on 30 g BOD_5/m²·day loading limit
Number of RBC Shafts	74	Each shaft provides ~14,085 m² media
Organic Loading (Stage 1)	30 g BOD_5/m²·day	US EPA maximum recommended
Hydraulic Loading Rate (HLR)	0.062 m³/m²·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 BOD_5 Reduction in RBC System

Stage	**Media Area (m²)**	**A/Q (m²·d/m³)**	**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.

VI. 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 its viability as an efficient, low-energy alternative to conventional suspended-growth systems. The four-stage RBC configuration was able to reduce BOD_5 concentrations from 479 mg/L in the influent to 13.3 mg/L in the final effluent, meeting international standards (<20 mg/L) for secondary wastewater treatment. These results are consistent with RBC performance benchmarks reported in international literature.

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 $BOD_5/m^2\cdot d$ in the first stage and ensured gradual pollutant reduction across subsequent stages. The hydraulic loading rate (HLR) of 0.062 $m^3/m^2\cdot d$ 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 BOD_5 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].

Several full-scale RBC systems worldwide have consistently achieved effluent BOD_5 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].

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.

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.

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[23-24]. Future efforts must therefore focus on policy facilitation, local capacity building, and donor engagement to translate this technically sound solution into a working infrastructure.

VII. Conclusion

This study provides a comprehensive engineering and environmental analysis for the implementation of a Rotating Biological Contactor (RBC) system in the Phase III expansion of the North Gaza Wastewater Treatment Plant (NGWWTP). The proposed design demonstrates the technical feasibility and operational advantages of RBCs in a high-load municipal wastewater treatment context, particularly under the constraints and challenges unique to the Gaza Strip.

From the primary analysis, the influent BOD_5 concentration (479 mg/L) and design flow (65,700 m^3/d) informed the sizing of the RBC system, requiring four treatment stages to achieve effluent standards below 14 mg/L. Each stage was carefully calculated based on empirical models (e.g., the Optaken equation), confirming that a modular arrangement of 74 shafts with optimized media surface area (1,049,010 m^2) is sufficient for BOD removal and nitrification.

Hydraulic and geometric parameters—including a hydraulic loading rate of 0.062 $m^3/m^2 \cdot d$ and retention time of 2.5 hours—were validated against international standards for combined organic and ammonia removal. Additionally, tank volume (85 m^3) and optimal submergence (40%) were aligned with best practices, confirming structural compatibility. The secondary clarification system utilizes circular clarifiers with bottom scrapers and deflection discs, designed for efficient sludge withdrawal and minimized short-circuiting. The clarifier sizing was optimized to be approximately 20% smaller than those used in conventional activated sludge systems, reflecting construction and land-use efficiencies. Noise and odour control measures were comprehensively incorporated, including fully enclosed mechanical units, suction systems, and biofilter installations. These systems are critical for maintaining environmental and social acceptance, particularly in densely populated areas like Gaza.

Compared to conventional activated sludge and membrane bioreactor systems, the Rotating Biological Contactor (RBC) presents several operational advantages, including lower energy requirements, reduced sludge production, and high scalability through modular design. These features make the RBC a technically attractive option for wastewater treatment in Gaza's constrained context. However, the feasibility of implementing such systems remains dependent on critical external factors. These include the availability of construction materials under ongoing import restrictions, the development of a trained workforce for operation and maintenance, and the financial sustainability of the project which requires comprehensive cost-benefit assessments and engagement with potential funding sources. Addressing these contextual challenges is essential to ensure the long-term success and resilience of decentralized wastewater treatment in the region.

This study confirms that the RBC system is technically sound, environmentally appropriate, and economically promising for wastewater treatment in Gaza. It provides a resilient, energy-efficient, and modular solution that can adapt to both current and future treatment needs. The next steps must involve policy coordination, funding mechanisms, and local capacity-building to transition this design into practical implementation.

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