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Comparative Study of RBC-based Dairy Wastewater Treatment with and without Aeration

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***Abstract*— In this paper, the dairy sector in India is a major contributor to water pollution, as it generates high organic load wastewater from production and processing operations, resulting in severe environmental issues. This paper presents a comparative analysis of a laboratory-scale Rotating Biological Contactor (RBC) system with coir rope as a new low-cost biome dial material for treating Amul dairy wastewater. The experimental setup was operated at a constant disc speed of 4.5 rpm, and the experiments were carried out under two different conditions: with and without aeration. The key performance parameters, such as chemical oxygen demand (COD) removal efficiency, biochemical oxygen demand (BOD) reduction, and overall treatment efficiency, were analysed in depth. The results clearly show that the coir rope RBC system outperformed the conventional systems and has great potential as a sustainable and economical treatment solution for dairy wastewater.**

***Index Terms*— COD, BOD, TDS, pH, turbidity, nitrate, and sulphate to determine treatment efficiencies.**

I. INTRODUCTION

In recent years, the Indian dairy sector has expanded at a rapid rate, leading to a large increase in the production of high-strength wastewater, as 6-10 L of wastewater is produced per litter of milk processed. This high-strength wastewater, rich in organic materials, often exceeds the CPCB discharge standards and can cause serious environmental problems if discharged without treatment. Conventional activated sludge processes are costly to operate, and hence, Rotating Biological Contactors offer a promising alternative. In this work [1],[2], a multi-stage RBC with low rotational speed (4.5 rpm), coir rope as a low-cost bio-carrier, and 45% submergence was used to treat VASUDHARA DAIRY NAGPUR wastewater effluent under both aerated and non-aerated conditions. The treatment efficiency was evaluated using key parameters—COD, BOD, TSS, TDS, pH, turbidity, nitrate, and sulphate—to formulate a cost-effective dairy wastewater treatment strategy specifically suited to the Indian scenario.

A. Selection of RBC to Treat Dairy Wastewater

The Rotating Biological Contactor (RBC) is a special case for the treatment of dairy wastewater, as it can easily handle high organic loads with less energy consumption and simple mechanisms compared to the activated sludge process [3],[4].

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The combination of the revolving discs and the biological growth layer is the best for oxygen transfer and degradation of wastes in a compact space, which is suitable for energy- and space-starved plants like VASUDHARA DAIRY NAGPUR. The previous research showing the removal of BOD up to 96% and the removal of COD are good for this purpose too.

B. Working of Rotating Biological Contactor (RBC)

In the Rotating Biological Contactor [RBC] system, semi-submerged rotating discs (speed range of 2-10 rpm) utilize biofilm that degrades organic matter in dairy wastewater by aerobic digestion. The discs rotate to expose the effluent (substrate) and air (oxygen) alternately. Sloughing action prevents biofilm buildup. Important parameters that affect RBC performance include disc speed, disc surface area [1],[14], submergence of 40-50%, and biofilm media used (geotextile is used in RBCs to encourage microbial growth). RBC has advantages like easy operation, low energy requirement, and high removal efficiency of BOD, COD, and turbidity.

C. Materials and Methods

Wastewater

The dairy wastewater used in this study was obtained from Vasudhara Dairy Nagpur (Hingna area) processes milk and ice-cream with a capacity of approximately 7.20 LLPD as part of the union's total 14.20 LLPD across sites (Nagpur and Bosier in Maharashtra contributing ~7.20 LLPD). Historical expansions include plans from 100,000 LPD to 200,000 LPD, aligning with ~80,000-200,000 LPD reports for Nagpur.

Fabrication of Rotating Biological Contactor

Reactor Tank: A semi-circular tank with a total capacity of 25 litres was fabricated to serve as the reactor. A cuboid-shaped stand was manufactured to provide a stable support structure for the tank.

Rotating Assembly: Two bearings were placed on opposite ends of the tank to support a 2 cm diameter stainless steel shaft. A total of 10-14 circular discs were fabricated. Each disc had a diameter of 20 cm and a thickness of 5 mm. These were fixed to the shaft, maintaining a clear spacing of 2.5 cm between them.

Drive system: We fixed a low RPM DC geared motor at one end of the shaft and connected it to a speed controller to provide a constant speed of 4.5 RPM.

Aeration system: The principal modification involved the installation of 3-4 fine-pore diffusers around the bottom of the tank, which was connected to an external air pump to provide a constant supply of dissolved oxygen to the wastewater [4].

In Figures 1 and Figure 2 the RBC system is depicted, with Figure I being the schematic representation and Figure II being the actual laboratory setup.

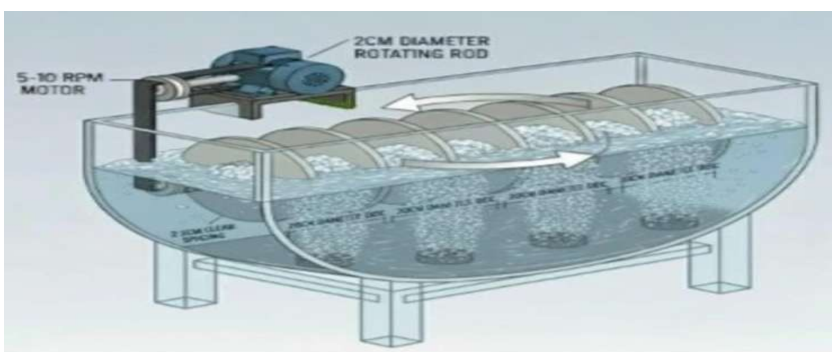

Figure 1. Dimensional View of an RBC System

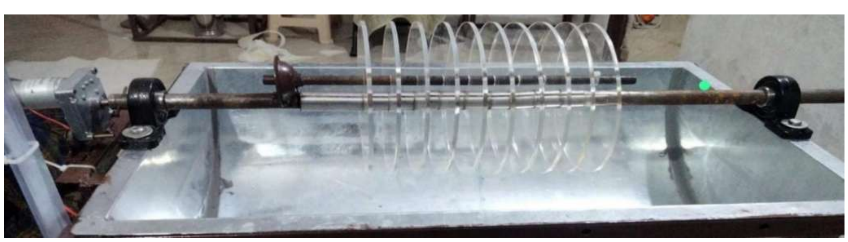

Figure 2. Actual Setup of an RBC System

II. METHODOLOGY

A. Identification and Finalization Of Industry

Several dairy industries in Nagpur were surveyed for wastewater characteristics; Vasudhara Dairy (Hingna) was shortlisted due to its high-volume milk/ice-cream processing generating typical high-BOD effluent (1000-3000 mg/L) [1],[2],[10].Vasudhara Nagpur plant, part of Valsad District Coop Milk Producers Union, has ~80,000 LPD capacity (historical data), with expansions to support 7.20 LLPD across Maharashtra units, ideal for RBC scalability studies Finalized after site visits to ensure accessibility, availability of fresh effluent, and relevance to small-medium Indian dairy operations (80,000-200,000 LPD capacity) .Effluent characteristics (high COD, fats, and TSS from milk processing) align with RBC literature, allowing for direct comparison of treatment effectiveness .Close proximity to research facility ensured minimal degradation of samples, allowing for accurate RBC performance data.

B. Design of Model

The design of the model is aimed at creating a laboratory-scale Rotating Biological Contactor (RBC) system that is capable of efficiently treating dairy wastewater. Some of the factors that are taken into consideration in the design of the model include the size of the reactor tank, the number and size of the discs, the design of the shaft, and the ability to have partial submergence of the discs in the wastewater. These parameters are selected to ensure sufficient surface area for microbial biofilm development and adequate contact between the wastewater, microorganisms, and atmospheric oxygen. In addition, operational parameters such as rotational speed, hydraulic retention time, and loading conditions are incorporated into the model design to simulate practical treatment conditions [4],[5],[9]. The design also allows flexibility for incorporating different media and adjusting operating conditions as required. Overall, the model is designed to ensure stable operation, ease of monitoring, and reliable evaluation of the performance of the RBC system in treating dairy effluent [5],[12],[15].

C. Identification and Finalization Of Media

Common RBC media like plastic discs are costly and less biodegradable; coir rope (coconut fibre) selected for its high surface area (~2000 m^2/m^3), low cost, and natural biofilm support Coir rope offers superior microbial attachment due to fibrous structure, porosity, and resistance to clogging, outperforming synthetic media in organic-rich dairy wastewater .Locally available in India (abundant coconut waste), eco-friendly, and durable under rotation (5-10 rpm), reducing operational costs for small dairy plants .Literature confirms coir fibre's efficacy in fixed-film systems (e.g., 80-90% BOD removal), justifying its use over conventional media for sustainable RBC design .Finalized after lab trials showing quick biofilm formation (7-10 days) and no degradation in dairy effluent (high fats/COD), ideal for Nagpur study conditions [5],[8],[11].

D. Fabrication of Model

Assembled the lab-scale RBC unit with reactor tank, discs mounted on the central shaft, motor drive, bearings, and speed controller, ensuring proper fit and function. Pre-tested the unit to ensure there were no leaks, it was robust, and the discs turned evenly at 4.5 rpm before actual experiments[8],[13].

E. Collection of Dairy Wastewater Sample

Collected two samples of 2L from Vasudhara Dairy using standard grab sampling techniques, transporting them to the lab at 25°C. Sample 1: Un-aerated (settling only). Sample 2: Aerated (72 hours continuous). Monitored initial/post parameters such as pH, BOD, COD, turbidity, TDS, sulphate, and nitrate.

F. Wastewater Treatment Methodology

Without Aeration Treatment - Initial tests were conducted on the dairy wastewater sample. Then, 35 Liters of wastewater was added to the RBC (Rotating Biological Contactor) model tank, with disc speed set at 4.5 rpm. The discs were rotated continuously for 72 hours, after which f final readings were taken for parameters like pH, BOD, COD, Turbidity, Sulphate, Nitrate and TDS [1],[13],[15].

With Aeration Treatment - Initial tests will be carried out on the dairy wastewater sample to determine basic parameters (such as pH, BOD, COD, TDS, Sulphate Nitrate and Turbidity). Then, 35 litres of wastewater will be added to the tank of the Rotating Biological Contactor (RBC) model, and the disc speed will be maintained at 4.5 rpm while the diffuser is switched on to provide aeration. The discs will be rotated continuously for 72 hours, after which the final readings of the selected parameters will be taken to evaluate the treatment performance [1],[2],[3].

The extent of treatment achieved under with aeration and without aeration conditions will be evaluated by comparing the measured parameter values (pH, BOD, COD, TDS, Turbidity, Sulphate and Nitrate) obtained after treatment in each case. The final values will be used to calculate the percentage reduction for each parameter, and these results will then be compared to determine in which condition the wastewater has been treated more effectively [2],[5].

III. RESULT

A. Test Result of Treatment Wastewater without Aeration

TABLE I: TEST RESULT OF TREATMENT WASTEWATER WITHOUT AERATION

Parameters	Initial Result of Dairy Wastewater (Without Treatment)	Final Result of Treated Wastewater (Without Aeration)	Efficiency of Removal (%)
pH	6.624	7.332	-
Turbidity	67NTU	13NTU	80.59
COD	1900mg/l	190mg/l	90
BOD	520mg/l	58mg/l	88.84
TDS	644mg/l	543mg/l	15.68
Sulphate	1.377mg/l	0.881mg/l	36.02
Nitrate	2.432mg/l	0.81mg/l	66.69

Table I present the test results for the treatment of wastewater without aeration. These results illustrate the performance of the treatment process under non-aerated conditions.
pH: The pH increased from 6.624 to 7.332, which shows an increase in alkalinity.
Turbidity: The turbidity was greatly reduced from 67 NTU to 13 NTU, with a removal efficiency of 80.60%, which shows excellent removal of suspended and colloidal matter.
BOD (Biochemical Oxygen Demand): BOD was reduced from 520 mg/L to 58 mg/L, with a removal efficiency of 88.84%, which shows outstanding removal of biodegradable organic matter.
COD (Chemical Oxygen Demand): COD was reduced from 1900 mg/L to 190 mg/L, which shows a 90% removal efficiency, indicating outstanding oxidation and removal of organic matter.
TDS (Total Dissolved Solids): TDS slightly reduced from 644 mg/L to 543 mg/L, with a positive removal efficiency of 15.68%, which shows slight removal of dissolved solids.
Sulphate: There was a reduction in the sulphate concentration from 1.377 mg/L to 0.881 mg/L, with a moderate removal efficiency of 36.02%.
Nitrate: The concentration of nitrate was reduced significantly from 2.432 mg/L to 0.81 mg/L, with a high removal efficiency of 66.69%, which is an indication of efficient denitrification reactions.
Overall Performance: The overall performance of the treatment process (without aeration) is excellent in removing COD (90%), BOD (88.84%), turbidity (80.60%), nitrate (66.69%), sulphate (36.02%), and TDS (15.68%). The increase in pH may be due to biological reactions

B. Test Result of Treatment Wastewater With Aeration

TABLE II: TEST RESULT OF TREATMENT WASTEWATER WITH AERATION

Parameters	Initial Result of Dairy Wastewater (Without Treatment)	Final Result of Treated Wastewater (With Aeration)	Efficiency Removal (%)
pH	6.624	7.560	-
Turbidity	67NTU	5NTU	92.53
COD	1900mg/l	110mg/l	94.21
BOD	520mg/l	32.6mg/l	93.73
TDS	644mg/l	548mg/l	14.90
Sulphate	1.377mg/l	0.745mg/l	45.89
Nitrate	2.432mg/l	0.218mg/l	91.03

Table II present the test results for wastewater treatment with aeration.
pH: The pH value increased from 6.624 to 7.560, showing an increase in alkaline nature after treatment.
Turbidity: The turbidity was reduced to a great extent from 67 NTU to 5 NTU, with a removal efficiency of 92.53%, signifying excellent removal of suspended and colloidal matter.
BOD (Biochemical Oxygen Demand): The BOD value decreased from 520 mg/L to 32.6 mg/L, with a removal efficiency of 93.73%, signifying outstanding removal of biodegradable organic matter.

COD (Chemical Oxygen Demand): The COD value reduced from 1900 mg/L to 110 mg/L, with a removal efficiency of 94.21%, signifying outstanding oxidation and removal of organic matter.
TDS (Total Dissolved Solids): The TDS value slightly reduced from 644 mg/L to 548 mg/L, showing a positive removal efficiency of 14.89%, signifying the removal of dissolved solids.
Sulphate: The concentration of Sulphate decreased from 1.377 mg/L to 0.745 mg/L, thus ensuring a removal efficiency of 45.89%, which is a remarkable reduction.
Nitrate: Nitrate has been removed to a large extent from 2.432 mg/L to 0.218 mg/L, thus ensuring a removal efficiency of 91.03%, which is a remarkable achievement.
Overall Performance: The overall performance of the treatment process (without aeration) is excellent, and it has performed better in removing COD (94.21%), BOD (93.73%), Turbidity (92.53%), Nitrate (91.03%), Sulphate (45.89%), and TDS (14.89%). The rise in pH values can be attributed to biological reactions or media interaction, as all major parameters have shown significant improvement in this experiment compared to the previous [1],[4],[6].

C. Comparative Analysis of Treated Wastewater using RBC (Without Aeration and with Aeration)

TABLE III: COMPARATIVE ANALYSIS OF TREATED WASTEWATER USING RBC (WITHOUT AERATION AND WITH AERATION)

Parameter	Efficiency of Treated Wastewater Without Aeration (%)	Efficiency of Treated Wastewater with Aeration (%)
pH	-	-
Turbidity	80.59	92.53
BOD	88.84	93.73
COD	90.00	94.21
TDS	15.68	14.90
Sulphate	36.02	45.89
Nitrate	66.69	91.03

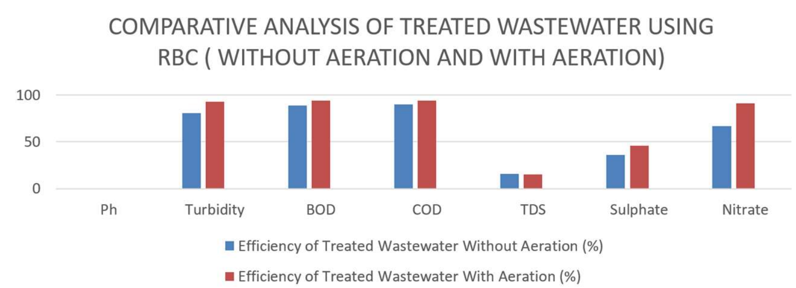

Figure 3 Comparative Analysis of Treated Wastewater Using RBC (Without Aeration and with Aeration)

Table III and Figure 3 present a comparative analysis of treated wastewater using the Rotating Biological Contactor (RBC) under both without aeration and with aeration conditions [6],[7],[8]. These visuals highlight key differences in treatment performance, The comparison reveals enhanced outcomes with aeration, demonstrating its role in optimizing RBC system effectiveness.

IV. CONCLUSIONS

The RBC system proved to be highly efficient for dairy wastewater treatment, and aeration contributed significantly to all parameters. Without aeration, the removal efficiencies were turbidity (80.59%), BOD (88.84%), COD (90%), TDS (15.68%), sulphate (36.02%), and nitrate (66.69%). With aeration, the removal efficiencies were significantly higher for turbidity (92.53%), BOD (93.73%), COD (94.21%), sulphate (45.89%), and nitrate (91.03%), but slightly lower for TDS to 14.90%. Aeration contributed significantly to the improvement (+13% average improvement) in nitrate (+24.34%) and sulphate (+9.87%) removals, with >90% removal of organics. The aerated system design gives CPCB-satisfactory effluent (BOD < 50 mg/L, COD < 250 mg/L) and is an optimized and trustworthy design for high-strength dairy[10], [12], [14].

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