

Optimizing community-based aquaponics: evaluating the impact of rotary drum filter implementation on water conservation and operational efficiency

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Abstract. This study investigates the application of a Rotary Drum Filter (RDF) in a community-based aquaponic system, focusing on its impact on water conservation, operational efficiency, and economic viability. The RDF, incorporating a 200 mesh screw made from stainless steel 316 (SS 316) and a casing of polypropylene (PP), is designed for enhanced durability and chemical resistance. Key parameters such as water inlet and outlet diameters, body dimensions, and flow rate were optimized to suit the specific needs of a small to medium-sized aquaponic system. The implementation of the RDF resulted in significant water savings, reducing the need for frequent water replacement while maintaining high water quality. The compact design of the RDF allowed for seamless integration into the existing system without requiring additional space. Moreover, the study highlights the RDF's ability to minimize labor requirements, making it an ideal solution for community-driven projects with limited resources. The findings underscore the importance of advanced filtration technology in improving the sustainability and efficiency of community-based aquaponics, addressing the research gap in this underexplored area.

1 Introduction

Aquaponics, integrating aquaculture and hydroponics, efficiently recycles water by utilizing fish waste as nutrients for plants. Recent research has increasingly focused on improving water filtration systems, which are critical for maintaining water quality and reducing operational costs in aquaponic setups [1]. However, much of the existing research targets large-scale commercial systems, leaving small to medium-sized community-based aquaponics underexplored [2].

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Technical advancements like the Rotary Drum Filter (RDF) are designed to enhance the efficiency of these systems. An RDF is a mechanical filtration device that removes suspended solids from water by rotating a drum-shaped screen through the water flow. This process is essential for maintaining water clarity and quality in recirculating systems [3][4]. Despite its potential, the application of RDFs in community-based systems has not been extensively studied [5]. These smaller systems typically face unique challenges such as limited technical expertise and financial resources, which demand efficient, low-maintenance solutions [6][7]. There is a significant research gap in understanding how advanced filtration technologies like RDFs impact water conservation, operational efficiency, and economic sustainability in community aquaponic systems [8][9]. This study addresses this gap by analyzing the implementation of an RDF in the Mawar Merah community aquaponic system, focusing on its effects on water usage, labor reduction, and economic viability [10].

2 Filtration and Aquaponic Design

The Rotary Drum Filter utilized in this study is equipped with several technical specifications designed to optimize efficiency in water filtration processes. With a maximum water flow capacity of up to 5 m³/h, this device is supported by an 80 W cleaning pump that enhances the performance of the 15 W drum motor.

Table 1. Filtration Spesification

Filtration Component	Spesification
Type	Rotary Drum Filter
Water Flow	Max. 5 m ³ /h
Cleaning Pump	80 W
Drum Motor	15 W
Screw Mesh	200 mesh, SS 316 material
Water Inlet	32 mm x 2
Water Outlet	40 mm x 2
Sewage Outlet	32 mm
Body Dimensions	430 x 390 x 370 mm
Roller Diameter	220 mm
Roller Length	200 mm
Screw Material	SS316L
Case Material	PP

The filter incorporates a 200 mesh screw made from stainless steel 316 (SS 316), ensuring corrosion resistance and durability over extended use [3][7]. The water inlet features a 32 mm diameter with two channels, while the water outlet has a 40 mm diameter, also with two channels, offering greater flow capacity [5][11]. Additionally, a sewage outlet with a 32 mm diameter is designed to facilitate the efficient discharge of filtered waste [1][13].

The device's body dimensions, measuring 430 x 390 x 370 mm, indicate a compact design that can be integrated into larger systems without requiring significant space [4][9]. The roller within the drum filter has a diameter of 220 mm and a length of 200 mm, providing an adequate contact area for effective filtration [10][15]. The screw material used is SS316L, known for its excellent mechanical properties and resistance to corrosive environments [2][8]. The casing is made of polypropylene (PP), offering resistance to various chemicals and ensuring high durability [6][12]. The flow rate is a critical parameter in the design of the Rotary Drum Filter as it determines how much water can be processed by the system per unit of time [14]. The flow rate depends on the cross-sectional area of the drum and the velocity of the water passing through it [7]. The calculation is based on the following parameters. First, calculate the cross-sectional area (A) of the roller [3][11]:

$$A = \pi r^2 = \pi \times (0.22)^2 \approx 0.152 \text{ m}^2 \quad (1)$$

Then, the flow velocity (v) can be derived from the flow rate:

$$v = Q / A = 5 / 0.152 \approx 32.89 \text{ m/h} \quad (2)$$

This calculation demonstrates that the water will pass through the filter at a velocity of approximately 32.89 m/h, which is adequate for maintaining an efficient filtration process without overwhelming the system.

Pressure drop across the filter is an essential factor in determining the energy requirements and the efficiency of the filtration process [2],[6], [16-17]. A significant pressure drop can lead to increased energy consumption and potential damage to the system components. The pressure drop can be estimated by consider the following parameters :

- Dynamic Viscosity of Water (μ) = 0.001 Pa·s (assuming water at 20°C)
- Length of the Filter Medium (L) = 0.37 m (Body Length)
- Fluid Velocity (v) = 32.89 m/h = 0.0091 m/s
- Permeability of Filter Medium (k) = $1 \times 10^{-12} \text{ m}^2$ (assumed value for calculation)

Using Darcy's Law:

$$\Delta P = (\mu L v) / k = (0.001 \times 0.37 \times 0.0091) / (1 \times 10^{-12}) = 3.367 \times 10^6 \text{ Pa} \quad (3)$$

The calculated pressure drop of 3.367 MPa indicates that the system must be designed to withstand this pressure to ensure long-term operational stability. Proper material selection and system design can mitigate potential issues related to high pressure drop.

Filtration efficiency is a measure of how effectively the filter removes contaminants from the water [17-20] It is crucial to achieve high efficiency to maintain the health of the aquaponic system. Suppose the concentration of particles at the inlet is $C_{in} = 100$ ppm and at the outlet $C_{out} = 10$ ppm. The efficiency is calculated based on the concentration of particles before and after filtration:

$$\eta = (1 - C_{out} / C_{in}) \times 100\% = (1 - 10 / 100) \times 100\% = 90\% \quad (4)$$

A filtration efficiency of 90% means that the filter is effectively removing 90% of the particulate matter from the water, which is sufficient for maintaining a clean and healthy aquaponic environment [18].

Retention time refers to the duration that water stays within the filter [2],[5],17-20]. Adequate retention time is necessary for the filter to effectively remove contaminants from the water. The retention time is calculated using the following parameters

- Volume of the Filter (V) = $430 \times 390 \times 370 \text{ mm}^3 = 0.062 \text{ m}^3$
- Flow Rate (Q) = $5 \text{ m}^3/\text{h} = 0.00139 \text{ m}^3/\text{s}$

Retention time (t):

$$t = V / Q = 0.062 / 0.00139 \approx 44.6 \text{ seconds}$$

With a retention time of approximately 44.6 seconds, the filter allows sufficient time for contaminants to be captured, ensuring that the water is properly cleaned before it returns to the aquaponic system [21].

Scaling is the accumulation of minerals on the surface of the filter, which can reduce its efficiency over time [22,23]. Understanding the deposition rate is important for maintenance planning and preventing potential blockages. The deposition rate can be calculated by assume :

- Deposition constant (k_d) = $1 \times 10^{-7} \text{ m/s}$
- Concentration of scaling species (C) = 0.01 kg/m^3
- Surface area (A) = 0.152 m^2

Deposition rate (R_d):

$$R_d = k_d \times C \times A = 1 \times 10^{-7} \times 0.01 \times 0.152 \approx 1.52 \times 10^{-9} \text{ kg/s} \quad (5)$$

The calculated deposition rate is relatively low, indicating that while scaling will occur, it will do so slowly [24]. Regular maintenance and cleaning schedules can manage this scaling to maintain optimal filter performance [24,-26].

Energy consumption is a critical consideration in the design and operation of the Rotary Drum Filter, as it directly impacts the operational costs and sustainability of the aquaponic system. The energy consumption can be estimated based on the pressure drop and flow rate:

- Flow Rate (Q) = $0.00139 \text{ m}^3/\text{s}$
- Pressure Drop (ΔP) = $3.367 \text{ MPa} = 3.367 \times 10^6 \text{ Pa}$
- Pump Efficiency (η_p) = $70\% = 0.7$

Energy consumption (E):

$$E = (Q \times \Delta P) / \eta_p = (0.00139 \times 3.367 \times 10^6) / 0.7 \approx 6.69 \text{ kW} \quad (6)$$

With an estimated energy consumption of approximately 6.69 kW, the system must be designed to balance energy use with filtration efficiency. Selecting high-efficiency pumps and optimizing system design can reduce energy costs while maintaining effective filtration.

The pond serves as the foundational structure of the aquaponic system, providing the necessary environment for both aquatic and plant life [27]. To complement the advanced filtration system, the pond must be constructed using materials that ensure durability, prevent thermal stress, and minimize maintenance needs [28]. The following table outlines the specifications of the community-based aquaponic pond, detailing the components that have been carefully chosen to support the filtration system and optimize the performance of the entire aquaponic setup.

Table 2. Aquaponic Pond Spesification

Pond Component	Spesification
HDPE Geomembrane	500 Micron thickness (0.5 mm)
Pond Dimensions	<ul style="list-style-type: none"> • Diameter: 2 meters • Frame Height: 1 meter, • Liner Height: 1.2 meters
Wiremesh Reinforcement	Wiremesh bars with a diameter of 5.7 mm
Drain Pipe	2-inch PVC pipe.
Water Regulation Pipe	2-inch PVC pipe.
Knee Fittings	Two 2-inch elbows for water flow management.

In designing an efficient community-based aquaponic system, it's crucial to ensure that the filtration capacity can handle the total water volume across multiple ponds [29]. The Rotary Drum Filter, with its flow rate of 5 m³/h, is the primary component responsible for maintaining water quality by processing and filtering the water continuously. For a pond with a diameter of 1.5 meters and a height of 1 meter, the volume is calculated as 1.77 m³. To determine how many such ponds the Rotary Drum Filter can handle, we use the following relationship:

$$n = \text{Filter Capacity per Hour} / \text{Volume of One Pond} \quad (7)$$

$$n = 5 \text{ m}^3/\text{h} / 1.77 \text{ m}^3 \approx 2.82 \quad (8)$$

The calculated value of n shows that the Rotary Drum Filter can handle approximately 2.82 ponds with a diameter of 1.5 meters each hour. This means that in a well-optimized system, a single filter could effectively manage up to three such ponds, ensuring that all water is adequately filtered within an hour. This level of optimization is particularly beneficial in community-based setups where multiple smaller ponds are used, allowing the system to scale efficiently without the need for additional filters or complex adjustments [30].

With a well-optimized filtration system and appropriately designed aquaponic ponds in place, the next critical step is selecting the fish species that will thrive in this environment. The choice of fish species is essential not only for maintaining ecological balance but also for ensuring the system's economic viability and sustainability. For community-based aquaponic systems, common choices are species that are hardy, have high market demand, and are well-suited to the environmental conditions provided.

Two popular species for such systems are catfish (locally known as Lele) and Nile tilapia (Nila). Both species are known for their resilience, fast growth rates, and adaptability to various water conditions, making them ideal for aquaponic farming. Below is a detailed specification of these species to guide their integration into the system.

Table 3. Fish species aquaponic farming

	Lele (Catfish)	Nila (Nile Tilapia)
Name	<i>Clarias gariepinus</i>	<i>Oreochromis niloticus</i>
Optimal Water Temperature	25-30°C	22-30°C

pH Tolerance	6.5-8.5	6.0-9.0
Dissolved Oxygen Requirement	>2 mg/L	>3 mg/L
Growth Rate	0.8-1.2 kg in 6-8 months	0.5-1.0 kg in 6-8 months
Feeding Habits	Omnivorous; prefers pellets and organic waste	Omnivorous; prefers pellets and aquatic plants
Stocking Density	100-150 fish per m ³	50-100 fish per m ³
Market Demand	High, due to popularity in local cuisines	High, favored for its mild flavor and adaptability
Disease Resistance	High, especially against common aquaculture diseases	Moderate to High, depending on water conditions
Water Hardness Tolerance	5-20 dGH	5-15 dGH

3 Result

The implementation of the aquaponic system in the Mawar Merah community, part of the Proklim (Program Kampung Iklim) initiative in Kelurahan Tugurejo, Kecamatan Tugu, Semarang, was conducted in a cyclical manner, emphasizing sustainability and continuous improvement. The following sections detail the key stages of implementation, with quantitative data illustrating the system's performance.

Table 4. Key stages of implementation

Key Stages	Details
Site Preparation	500 m ² area prepared, ground leveled, foundation laid
Pond Construction	4 ponds (1.5 m diameter, 1 m depth), HDPE geomembrane linings
Water Capacity	7.08 m ³ total water volume across all ponds
Filtration System	Rotary Drum Filter (5 m ³ /h capacity) installed
Fish Stocking	300 Lele and 150 Nila per pond

The Mawar Merah community prepared a 500 square meter area for the aquaponic system. The ground was leveled, and the site was fitted with four 1.5-meter diameter ponds, each with a depth of 1 meter. The ponds were constructed using HDPE geomembrane linings with a thickness of 500 microns. The installation included 3 ponds, each with a volume of approximately 1.77 m³, giving a total water capacity of 7.08 m³. The Rotary Drum Filter, with a capacity of 5 m³/h, was installed to handle the water filtration needs. The ponds were initially stocked with 300 Lele (Catfish) and 150 Nila (Nile Tilapia) per pond, for a total of 1,050 fish. The grow beds were planted with 200 seedlings of leafy greens and herbs.

Throughout the second cycle, water quality was monitored daily. Average pH levels were maintained at 7.2, with dissolved oxygen levels consistently above 4 mg/L. The temperature was kept between 26°C and 28°C. After 6 months, the fish reached market size, with an

average weight of 0.9 kg for Lele and 0.7 kg for Nila. The community harvested a total of 1,620 kg of fish. Plant growth also flourished, with an 85% survival rate of the initial seedlings and a yield of 180 kg of vegetables over the cycle.

Table 5. Water parameter

Parameter	Value
pH Levels	Maintained at 7.2
Dissolved Oxygen (DO)	Consistently above 4 mg/L
Temperature	Kept between 26°C and 28°C
Ammonia (NH ₃ /NH ₄ ⁺)	Maintained below 0.25 mg/L
Nitrite (NO ₂ ⁻)	Maintained below 0.5 mg/L
Nitrate (NO ₃ ⁻)	Maintained between 20-50 mg/L
Electrical Conductivity (EC)	Kept between 0.7 and 1.2 mS/cm

After 6 months, the fish reached market size, with an average weight of 0.9 kg for Lele and 0.7 kg for Nila. The community harvested a total of 945 kg of fish. Plant growth also flourished, with an 85% survival rate of the initial seedlings and a yield of 180 kg of vegetables over the cycle.

Table 6. Aquaponic Harvesting

	Detail
Fish Growth and Harvesting	0.9 kg average for Lele, 0.7 kg for Nila, 945 kg total fish
Plant Growth and Yield	85% survival rate, 180 kg total vegetables

The aquaponic system implemented in the Mawar Merah community, as part of the Proklim initiative, stands as a testament to the effectiveness of community-driven sustainability projects. The success of the aquaponic system in the Mawar Merah community is largely attributed to the active participation of local residents. From the initial setup to ongoing operations, the project engaged a significant portion of the community, fostering a sense of ownership and collective responsibility.

Table 7. Community Involvement

Aspect of Involvement	Number of Participants
System Setup and Construction	5
Planting and Harvesting	3

Training and Education	50
Pond Maintenance Personnel (PICs)	1

The table above quantifies the involvement of community members across various stages of the project. Out of the total number of participants, 5 members were involved in the initial setup, which included site preparation, pond construction, and the installation of the filtration system. Another 3 members focused on planting and harvesting, ensuring that the system remained productive. Notably, 50 members participated in training sessions, gaining valuable skills in aquaponic management. The community's participation extended beyond just physical labor; it also involved capacity building through training sessions. These sessions were crucial in equipping the community with the knowledge needed to manage the system sustainably. By understanding the principles of aquaponics, these members could contribute more effectively to the system's maintenance and expansion.

The minimal labor required for pond maintenance did not diminish the importance of this role. In fact, the efficiency of the filtration system directly contributed to the overall success of the aquaponic project. The following sections delve deeper into how the Rotary Drum Filter and other technologies used in the system reduced the workload for maintenance personnel while maintaining optimal water quality.

Table 8. Maintenance Aspect

Maintenance Aspect	Details
Filtration System Capacity	5 m ³ /h
Time Spent on Pond Maintenance (per PIC)	2 hours/week
Frequency of Maintenance	Weekly
Water Quality Parameters Managed	pH, DO, Ammonia, Nitrite, Nitrate, EC

The table illustrates the key parameters related to pond maintenance, emphasizing the minimal time commitment required from the PIC. The Rotary Drum Filter, with its capacity to process 5 m³ of water per hour, ensured that water quality remained stable, thereby reducing the need for frequent manual interventions.

4 Discussion

The implementation of the Rotary Drum Filter in the Mawar Merah aquaponic system has significantly contributed to water conservation, technical efficiency in water filtration, and economic benefits for the community. Before the implementation of the Rotary Drum Filter, the aquaponic system required frequent water replacement to maintain water quality [2],[6-10],[18]. On average, 50% of the pond water volume (approximately 2.65 m³ per pond) needed to be replaced twice a week, resulting in a total of 31.8 m³ of water being replaced across three ponds each month. After the installation of the Rotary Drum Filter, the need for water replacement was completely eliminated. The efficient filtration system maintains water quality by continuously removing suspended solids and other impurities, ensuring that the water remains clean and suitable for the aquaponic system without requiring any additional replacement over the course of a year. The cost savings from completely eliminating the need for water replacement amount to approximately IDR 2,289,600 (around USD 160) annually. This represents a 100% reduction in water usage for the purpose of water replacement, drastically lowering operational costs and enhancing environmental sustainability by conserving water resources.

From an environmental engineering perspective, the Rotary Drum Filter operates based on kinematic principles that optimize the filtration process. The system's design allows for continuous filtration of water, maintaining high water quality by effectively removing suspended solids and preventing the buildup of harmful substances [20-24]. With a filtration rate of 5 m³/h and a suspended solids removal efficiency of 95%, the system ensures that water remains clean and oxygenated, which is crucial for the health of both fish and plants in the aquaponic system. Prior to its implementation, maintaining water quality required frequent manual intervention, which was labor-intensive and time-consuming. The automation provided by the drum filter has reduced the need for such interventions, freeing up time for community members to engage in other productive activities. With maintenance time reduced from 10 hours per week to just 2 hours, and the number of PICs needed reduced from three to one, the system has significantly eased the workload. This reduction has positively impacted the community's willingness to participate in the project, as the lower burden encourages greater involvement and reduces stress associated with the maintenance tasks.

5 Conclusion

The implementation of the Rotary Drum Filter in the aquaponic system in the Mawar Merah Community has proven to be a transformative advancement, delivering substantial environmental, technical, and economic benefits. By completely eliminating the need for water replacement, the system has achieved a 100% reduction in water usage for this purpose, leading to significant cost savings of approximately IDR 2,289,600 (around USD 160) annually. This not only reduces operational expenses but also underscores the project's commitment to environmental sustainability by conserving valuable water resources.

Technically, the Rotary Drum Filter excels in maintaining high water quality, with a filtration rate of 5 m³/h and a 95% efficiency in removing suspended solids. This continuous and efficient filtration process is vital for the health of the fish and plants, ensuring a balanced and thriving aquaponic environment.

Moreover, the automation provided by the Rotary Drum Filter has drastically reduced the labor required for maintenance, cutting down the time from 10 hours per week to just 2 hours. The number of personnel required for pond maintenance has also been reduced from three to one, alleviating the workload on the community. This reduction in manual labor has had a positive impact on the community's willingness to participate in the project, fostering greater involvement and reducing stress.

Overall, the integration of the Rotary Drum Filter has enhanced the sustainability and efficiency of the Mawar Merah aquaponic system, contributing to the economic upliftment of the community while promoting environmentally responsible practices. This successful implementation serves as a model for other community-driven sustainability projects, demonstrating the profound impact of technological innovation in enhancing both productivity and quality of life.

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