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Research Article

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Design and Fabrication of a Laboratory Scale Hydromechanical Surface Floating Waste Collector Using River Flow

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Abstract

Unmanaged floating waste in rivers threatens aquatic ecosystems and sustainable water resource management. This study presents the design and experimental evaluation of a self powered floating waste collection system that operates exclusively using river flow energy.

The proposed device converts hydrodynamic energy into mechanical power through a rotating wheel driving a conveyor based collection mechanism. The effects of blade geometry and number, conveyor type and angle and guiding arm configuration were evaluated under real river conditions using representative floating debris and selected polymer wastes.

The optimal configuration, consisting of a 12 blade curved wheel, a modular conveyor belt inclined at 30°, and a rigid guiding arm, achieved a maximum collection efficiency of 83% at a flow velocity of 0.4 m/s. Collection efficiencies for PET and EPS reached 100%, while HDPE and LDPE achieved efficiencies of 93% and 84%, respectively. Comparison with existing technologies showed that the proposed system performed similarly to the River Cleaning System (85% efficiency). Furthermore, the efficiencies obtained for PET and EPS were consistent with those reported by Fuchs et al., reaching 100% under comparable flow conditions.

These results highlight the viability of energy autonomous hydromechanical systems as a sustainable solution for riverine waste management.

Keywords: Floating waste; Conveyor belt; Rotary wheel; Blade; Floating arm; Chain and sprocket.

Nomenclature

T	$Torque\ [N.m]$
F	$Force\ [N]$
M	$Mass\ (Kg]$
g	$Gravitational\ Acceleration\ [ms^{-2}]$
R	$Modular\ belt\ sprocket\ Radius\ [mm]$
T_{b30}	$Belt\ torque\ at\ 30^{\circ}\ [N.m]$
T_{b60}	$Belt\ torque\ at\ 60^{\circ}\ [N.m]$
T_{w30}	$Wastes\ torque\ at\ 30^{\circ}\ [N.m]$
T_{w60}	$Wastes\ torque\ at\ 60^{\circ}\ [N.m]$
T_b	$Belt\ torque\ [N.m]$
T_w	$Rotational\ Wheel\ torque\ at\ 60^{\circ}\ [N.m]$
z	$Number\ of\ gear\ teeth$
i	$Gear\ Ratio$
U	$Speed\ [ms^{-1}]$
L	$Blade\ length\ [m]$
w	$Blade\ width\ [m]$
d	$Radius\ of\ rotation\ [m]$

Greek symbol

ρ	$Water\ Density\ [Kgm^{-3}]$

Subscript

b	$belt$
w	$wastes$
rw	$rotary\ wheel$

Highlights

- Utilizing river flow as the driving force of the device.
- Investigating five independent variables to obtain the optimal system configuration.
- Assessing the efficiency of the device in processing various types of waste.

1. Introduction

Human activities in recent decades have affected all of Earth's habitats, from forests to oceans and rivers. As the world's population has surpassed 8 billion and the consumption of consumer goods has increased, the exponential growth of waste has become a global challenge. A significant portion of this waste is found in rivers and oceans, posing a serious threat to numerous aquatic species [1]

Rivers play a important role in the transport of land-based plastic waste from terrestrial sources to marine environments, acting as major conduits in the global plastic cycle [2]. When floating waste enters freshwater systems, it can remain for long periods and travel great distances, amplifying its environmental impact. These wastes affect a wide range of organisms, including fish, birds, invertebrates, and aquatic plants, through ingestion, entanglement, and the degradation of their natural habitats[3] and [4]. In addition to its environmental impacts, floating waste creates significant economic pressure on sectors such as fisheries, tourism, hydropower, and water infrastructure. It is estimated that the global costs associated with these effects range from 6 to 19 billion USD per year. [5] and [6].

To reduce these impacts, a variety of floating waste collection technologies have been developed in recent years. Passive systems such as the Seabin have demonstrated the ability to capture floating waste in controlled environments; however, the risk of unintentionally trapping aquatic organisms remains an issue. [7]. Barrier-based systems such as the Litter Gitter use floating booms to redirect waste toward collection points, preventing downstream transport in rivers. [8]. In addition, mechanically assisted systems incorporating conveyor belts and suction mechanisms have been proposed to enhance continuous waste removal from water surfaces [9].

Recent advances have also focused on automation and smart control technologies. Electrically powered and sensor-based systems, including Arduino-controlled devices and remotely operated platforms, have been developed to reduce human activites and improve operational efficiency [10]; [11]; [12]. Furthermore, mechanically driven rotating systems have been introduced to guide floating waste toward collection area using energy supplied by external power sources [13]. Despite these developments, most current solutions still rely on fossil fuel based or external energy sources. This dependency can limit their long term sustainability and make it more difficult to scale them effectively, especially in natural river environments. This dependence on external energy sources is a major limitation, especially when considering deployment in remote or large scale river systems, where maintaining a continuous power supply and regular maintenance can be challenging. In addition, many existing devices are designed for controlled or semi-controlled conditions and have limited ability to adapt to varying hydrodynamic conditions.

To address these limitations, the present study proposes and experimentally evaluates a self-powered floating waste collection system that operates exclusively using the kinetic energy of river flow. The system integrates a hydrodynamically driven rotary wheel coupled with two alternative waste transfer mechanisms, namely a modular conveyor belt and a chain-and-sprocket system. The influence of key design parameters, including conveyor inclination angle, blade geometry, blade number, and guiding arm configuration, was systematically investigated under real river conditions.

This work contributes to the development of sustainable and energy autonomous river cleaning technologies and supports global efforts toward reducing plastic leakage into aquatic ecosystems in line with circular economy principles and environmental protection goals.

2. Materials and Methods

2.1 Floating Waste Collector concept

The primary objective of floating waste collection systems is to intercept, transfer, and separate floating waste from the water surface under continuously varying hydraulic conditions. Due to the diversity of river geometries, flow characteristics, and waste properties, the design of such systems requires consideration of both hydrodynamic and mechanical constraints.

In the present study, a self-powered floating waste collection device was designed for rivers with a minimum water depth of 0.20 m and a maximum width of approximately 4.0 m. The system was intended to collect floating waste materials with characteristic dimensions up to 20 × 20 cm. The operational concept was based on utilizing the kinetic energy of river flow to drive a rotary wheel coupled to a waste transfer mechanism. The collected waste was subsequently transported to a storage tank using a conveyor-based system.

As shown in Fig. 1, the overall device consisted of five principal subsystems:
(1) Main structural frame,
(2) Conveyor belt system,
(3) Direction reversal and torque transmission
(4) Rotary wheel and blade system,
(5) Guiding and collection arms, and
(6) Stopping mechanism.

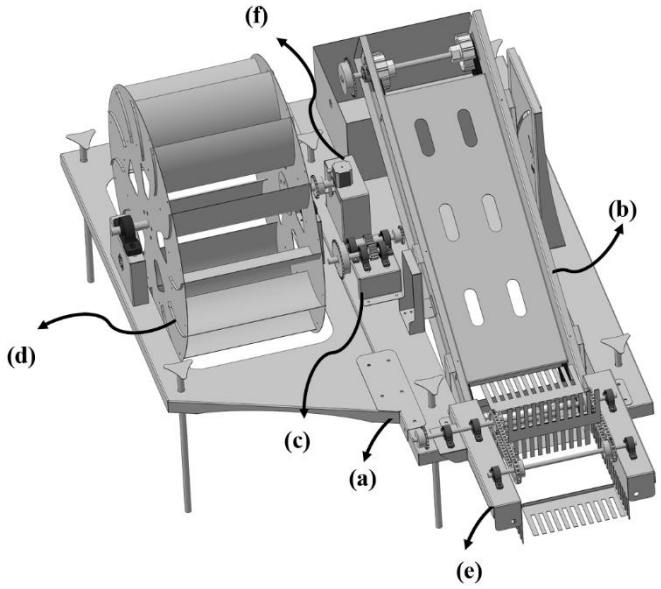


Fig. 1 Engineering Drawing, (a) Main Structural Frame, (b) Conveyor Belt System, (c) Direction Reversal and Torque Transmission, (d) Rotary Wheel and Blade Design, (e) Guiding Mechanism, (f) Stopping Mechanism

2.1.1 Main Structural Frame

The main structural frame served as the supporting platform for the rotary wheel, conveyor belt assembly, transmission gears, and waste storage tank. The frame was fabricated from 1.5 mm thick steel sheets reinforced through bending processes to improve structural rigidity under hydraulic loading conditions.

To enable operation under different river depths, the system was equipped with six adjustable support bolts allowing vertical positioning of the device. Considering the design constraints related with river dimensions and hydraulic stability, the final dimensions of the structure were selected as 135 × 113 cm.

2.1.2 Conveyor Belt System

The conveyor system was designed to transport floating waste from the water surface to the storage reservoir while overcoming hydrodynamic resistance and gravitational loading. A modular conveyor belt with a constant width of 255 mm was selected due to its corrosion resistance, structural flexibility, and ease of maintenance.

The total mass of the conveyor belt assembly was approximately 4 kg. In addition, 20 representative waste items with different sizes, densities, and geometries were selected to estimate the maximum transported load. The total mass of the collected waste samples was measured as 0.35 kg.

The torque required to rotate the conveyor belt was determined using [14]:

$$T = F * R \quad (1)$$

where T is the torque, F is the acting force, and R is the radius of the driving gear.

The acting force was calculated from the combined weight of the conveyor belt and transported waste:

$$F = Mg \quad (2)$$

where M represents the total mass and g is gravitational acceleration.

The torque demand was evaluated for conveyor inclination angles of 30° and 60°. The corresponding torque values were calculated as [15]:

$T_{b30} \cong 0.88\ Nm$, $T_{b60} \cong 1.52\ Nm$, $T_{w30} \cong 0.077\ Nm$ and $T_{w60} \cong\ 0.13\ Nm$

where T_b denotes the torque associated with the conveyor belt weight and T_w represents the torque generated by the transported waste. The total required torque for conveyor motion under the critical condition (60° inclination) was approximately 1.65 N·m.

To facilitate rapid experimental modification, the conveyor structure was designed in modular form, allowing interchangeability between the modular belt and chain-drive configurations. Furthermore, the side supports were designed with adjustable inclination capability between 30° and 60°.

2.1.3 Direction Reversal and Torque Transmission

Since the rotary wheel and conveyor belt rotated in opposite directions, a transmission mechanism was required to reverse rotational direction while simultaneously amplifying torque. This was achieved using a non-coaxial spur gear arrangement supported by KP002 bearings.

The transmission ratio was calculated using [16] and [6]:

$$\mathrm{i} = (\mathrm{Z}_2 \times \mathrm{Z}_4)/(\mathrm{Z}_1 \times \mathrm{Z}_3) = \mathrm{T_b}/\mathrm{T_{rw}} = 2.13 \quad (3)$$

where Z_1 , Z_2 , Z_3 , and Z_4 are the gear tooth numbers, and T_{rw} is the torque generated by the rotary wheel.

Using the selected gear configuration, the torque amplification ratio was obtained as 2.13. Consequently, the minimum required torque generated by the rotary wheel to initiate conveyor motion was determined as:

$$1.65/T_{rw} \cong 2.13 \ \rightarrow\ T_{rw} \cong 0.77\ \mathrm{N.m} \quad (4)$$

The gear arrangement employed in the transmission system is illustrated in fig. 2.

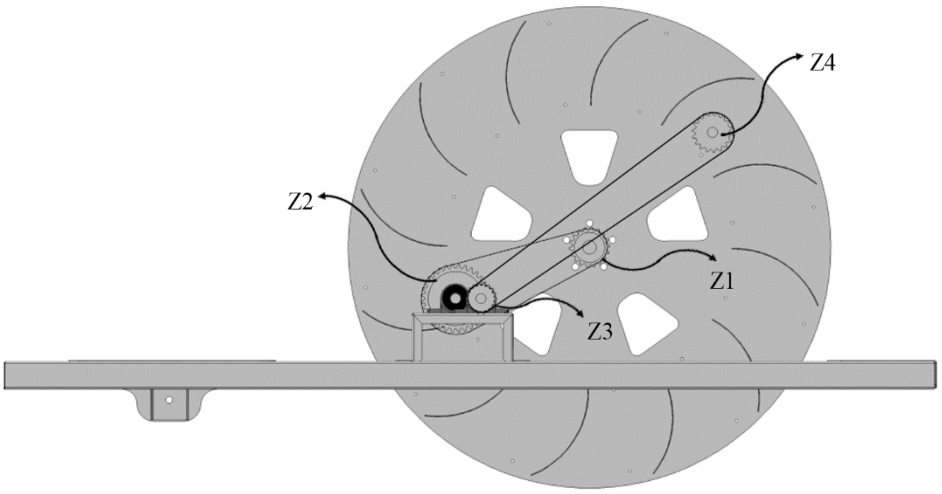


Fig. 2 The gears implemented

2.1.4 Rotary Wheel and Blade System

The rotary wheel was designed based on the hydraulic characteristics of Iranian rivers, where average flow velocities typically range between 0.3 and 1.0 m/s [17]. Since low flow velocity represents the critical operational condition for self-powered systems, a design velocity of 0.3 m/s was adopted.

The rotary wheel diameter was fixed at 70 cm. The hydrodynamic force exerted by the river flow on submerged blades was estimated using momentum conservation principles [18]:

$$F_{flow} = (\rho \times Q \times U) = (\rho \times A \times U \times U) \quad (5)$$

where ρ is water density, Q is flow rate, A is the wetted blade area, and U is flow velocity.

The generated torque on the rotary wheel shaft was then calculated as [19] (figure 3):

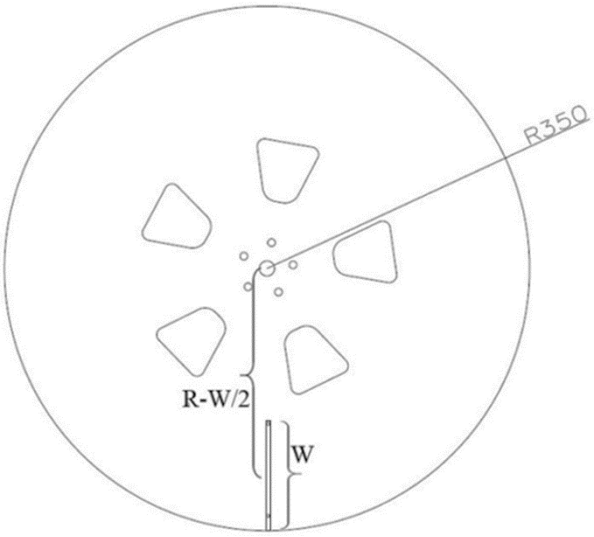


Fig. 3 Flat blade

$$T_{rw} \cong (\rho \times Q \times U) \times d = (\rho \times L \times w \times U \times U) \times (0.35 - w/2) \quad (6)$$

where L , w and d denote blade length, width and the distance between the center of the blade and the axis of rotation, respectively.

The minimum required blade width was calculated as approximately 8 cm. However, to ensure reliable performance under increased waste loading conditions, the final blade width was increased to 16 cm, while blade length was fixed at 35 cm.

Two blade geometries, namely flat and curved blades, were investigated. The curved blade profile was developed based on the hydrodynamic design proposed by [20] and scaled to fit the dimensions of the rotary wheel. Increasing the number of blades improves the performance of the rotary wheel [21] so, two blade number configurations (6 and 12 blades) were evaluated to investigate the effect of blade density on rotational performance.

2.1.5 Guiding Mechanism and Collection Arms

Due to local flow deceleration near the conveyor inlet, floating waste may deviate from the collection region. To improve waste guidance toward the conveyor entrance, a synchronized comb-like guiding mechanism was designed and coupled to the rotary wheel motion. This mechanism directed floating waste toward the conveyor blades while maintaining continuous movement synchronized with river flow conditions.

The dispersion of waste across the width of the river and the limited device inlet are factors that require the use of barriers to guide the waste toward the device inlet. Various designs are employed for this purpose. The most commonly used methods include floating booms [8] and bubble barriers [22]. For the floating boom design, insulating foam pipes with inner diameters of 40 mm and 20 mm were used, covered with a waterproof layer for protection. The arm of this design, with a rigid nature, was designed and constructed to be 200 cm long with a finished outer diameter of 10 cm . The second design uses fishing buoys to provide flotation for the structure and

a flexible rubber sheet to create wave-like motion for better waste transport. For this design, a flexible rubber sheet with a thickness of 2 mm and a width of 10 cm was used, along with fishing buoys measuring 15 × 4 cm . The height of the cover surface was designed to be 10 cm, and its length was 200 cm.

2.1.6 Stopping Mechanism

To enable continuous autonomous operation, an intelligent stopping mechanism was incorporated into the system. The mechanism consisted of a waterproof ultrasonic sensor (AJ-SR04M), an Arduino UNO R3 microcontroller based on the ATmega328P platform, and a CW42PH05 stepper motor. When the waste storage tank became full, the ultrasonic sensor detected the accumulated waste level. If the detected level persisted for more than 3s, the Arduino controller activated a rotating latch connected to the stepper motor. The latch rotated by 90° and mechanically blocked the rotary wheel shaft, thereby stopping system operation. This mechanism also enabled the transmission of a maintenance signal indicating the need for waste tank replacement. The operational sequence of the stopping system is presented in Figures 4 and 5.

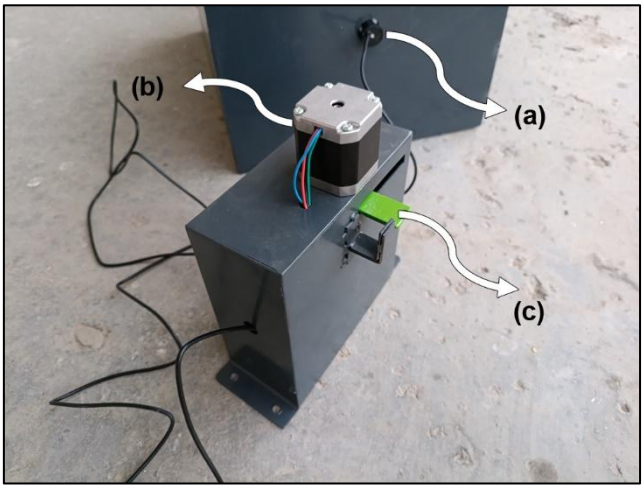


Fig. 4 Stopping mechanism, (a) Sensor, (b) Stepper motor, (c) Latch

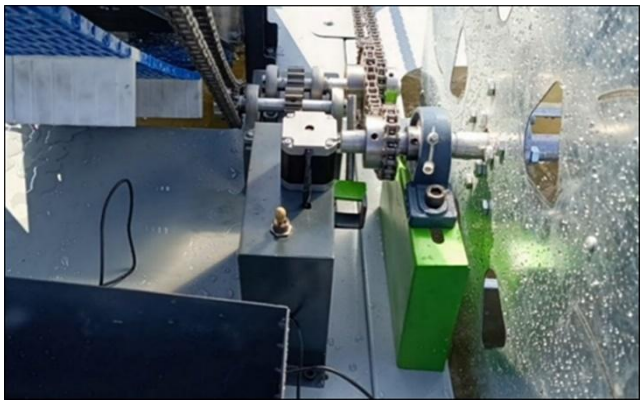


Fig. 5 Activated stopping mechanism

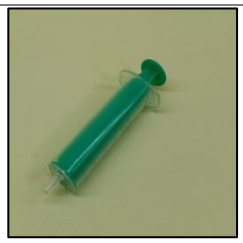
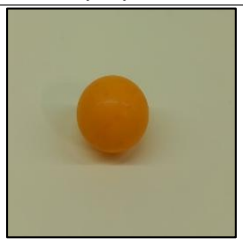
2.2 Prototype-Scale Experiments

2.2.1 Examined Materials

Since plastic composition exhibits high variability among different river catchments, along river courses, and over time [23] , and considering that [13] evaluated the performance of a plastic waste collection device using five specific polymeric waste types, this study incorporated both approaches. Therefore, both a diverse range of plastic waste and selected representative polymer types were considered in the experiments to better reflect real environmental conditions while also enabling controlled performance evaluation of the collection device.

To closely replicate real riverine conditions, commonly occurring wastes, introduced either naturally or through anthropogenic activities were selected. These included badminton shuttlecock, ping-pong ball, 10 cm diameter plastic ball, pine cone, wooden board, tree branche, intact and crushed mineral water bottle, metal beverage can, rope, pill container, syringe, spray bottle (HDPE), polyethylene foam, expanded polystyrene (EPS), rubber piece, toy, plastic item, mask, and food packaging (Table 1). The selected wastes represented a wide range of geometric shapes, including cylindrical, spherical, cuboid and irregular forms. This selection ensured diversity in both shape and density relative to water, thereby enhancing the realism of the experimental conditions.

Table 1 Selected waste materials representative of real river conditions

			
wooden board	Roup	Mineral water bottle (PET)	Crushed mineral water bottle
			
Spray Bottle (HDPE)	Polyethylene Foam	Pill container	Syringe
			
Badminton shuttlecock	Ping-pong ball	expanded polystyrene (EPS)	Metal beverage can
			
Pine cone	Tree branche	Rubber piece	Toy
			
Food packaging	Mask	plastic item (LDPE)	10 cm diameter plastic ball

Additionally, to achieve results comparable to those reported in [13], 20 samples of each waste polymer PET (polyethylene terephthalate), EPS (Expanded Polystyrene), HDPE (High density polyethylene), and LDPE (Low density polyethylene) were selected from materials representative of real river conditions (Table 1), in accordance with the three dimensional shapes presented in that study, and were tested separately. The densities and samples of the selected residues are presented in Table 2 and Table 3.

Table 2 Waste materials selected based on [13]

Materials	**PET**	**EPS**	**HDPE**	**LDPE**
Density $[\mathbf{gr/cm^3}]$	1.45	0.64	0.96	0.93

Table 3 Selected waste materials based on Study [13]

Study [13]				
This study				

2.2.2 Experimental Procedure

To evaluate the performance of the device, it was first necessary to determine the optimal variables for the defined components of the system, including the collecting arm, the slope and type of the conveyor belt, and the number and type of blades on the rotating wheel. Since two different configurations were designed and manufactured for each of the five variables, performance tests were conducted to identify and select the optimal configuration for each variable.

Once the optimal configuration of the device variables was determined, further experiments were conducted to evaluate the influence of river flow conditions on its performance, as well as to generate laboratory data for comparison with existing systems in this field. First, using the selected waste materials representative of those commonly observed in real river conditions (Table 1), the performance of the device under its optimal configuration was tested at different flow velocities.

The specifications of each variable are defined in the table 4.

Table 4 Specifications of each variable

A		B		C		D		E	
Collector arm		Belt		Slope		Blade shape		Number of blades	
A_1	Rigid	B_1	Modular	C_1	30°	D_1	Flat	E_1	6
A_2	Flexible Flexible	B_2	Chain and sprocket	C_2	60°	D_2	Curved	E_2	12

The optimal operating conditions of the device were determined through a five stage experimental procedure.

To evaluate variable A, the rigid collection arm (A_1) was first installed on the collector assembly (Figure 6). Twenty waste samples were released 5 m upstream, and the number of particles reaching the device inlet was recorded. The experiment was then repeated using the flexible arm (A_2) (Figure 7), and the results were compared to identify the more effective configuration.



Fig. 6 Rigid arm (A_1)



Fig. 7 Flexible arm (A_2)

For variable B, 20 waste samples were introduced directly at the device inlet, and the performances of the modular belt (B_1) (Figure 8) and the chain and sprocket system (B_2) (Figure 9) were assessed under identical operating conditions.



Fig. 8 Modular conveyor (B_1)



Fig. 9 Chain and sprocket (B_2)

In the case of variable C, the modular belt was selected and tested at inclination angles of 30° (C_1) and 60° (C_2). The inclination adjustment mechanism is shown in Figure 10.



Fig .10 belt slope ($C_1 and\ C_2$)

Finally, variables D (blade shape) and E (blade number) were examined. Flat blades (D_1) (Figure 11) and curved blades (D_2) (Figure 12), along with configurations of 6 blades (E_1) (Figure 13) and 12 blades (E_2) (Figure 14), were tested by releasing 20 waste samples within a fixed time interval. The performance of each configuration was then compared to determine the optimal operating setup. The performance of parameters D and E was evaluated by accounting for rotational speed, given its significant influence and the time-dependent nature of these parameters. Accordingly, a consistent reference time was selected for the comparison of the two variables. For the blade number parameter, the residue transfer time was first determined for the 12 blade configuration due to its higher rotational speed. This time was subsequently used as the reference criterion for measurements in the 6-blade experiments.



Fig. 11 Flat blade (D_1)



Fig. 12 Curved blade (D_2)



Fig. 13 Curved blade with 6 numbers (E_1)



Fig. 14 Curved blade with 12 numbers (E_2)

The performance of the device is primarily influenced by the power and rotational speed of the rotary wheel. The torque of the rotary wheel shaft was measured for four configurations using a torque meter. A calibrated Kobalt KDT-6 torque meter was employed for this purpose. By attaching this instrument to the rotary wheel shaft, the torque generated by the water flow to drive the rotary wheel was measured.

Another important parameter in this study is the rotational speed of the rotary wheel. Since the device's rotational speed was below 20 revolutions per minute, a marker was installed on the main shaft of the wheel, and the number of complete rotations of the marker within one minute was measured for four configurations.

2.2.3 Experimental Setup

The testing procedure was conducted in October, March, and April 2025 in the Safarood River, Iran, under varying water depths and a channel width of 300 cm. The main structure of the device was installed in the river such that the blades of the rotary wheel were fully submerged. This condition was achieved using six height-adjustment bolts. Throughout the testing period for choosing best variables, the main body of the device remained fixed, while the rotary wheel, conveyor belt mechanism, and guiding arm were replaced for different test configurations. Each test was repeated five times to ensure repeatability and reliability of the results.

The selection of the optimal configuration was carried out using the waste materials shown in Table 1 at a river flow velocity of 0.4 m/s. After identifying the optimal configuration, the device performance was evaluated at flow velocities of 0.7 and 1.1 m/s for both waste material groups, with each test repeated five times. The river conditions and testing schedule are presented in the table 5.

Table 5 Experimental procedure testing hydraulic and prototype parameters

Test time	October 2025	March 2025	April 2025
Flow velocity $[m/s]$	0.4	0.7	1.1
Flow depth $[cm]$	20	25	35
Reynolds number [-]	2.8×10^5	6.0×10^5	1.25×10^6

3. Results

Initially, to determine the optimal variables for the fabricated prototype, each of the five variables was tested independently following the procedure described. The experiments were conducted in a river with a flow velocity

of 0.4 m/s and a flow depth of 20 cm. Each variable was evaluated separately, and only its individual performance was recorded, without considering potential interactions with other variables.

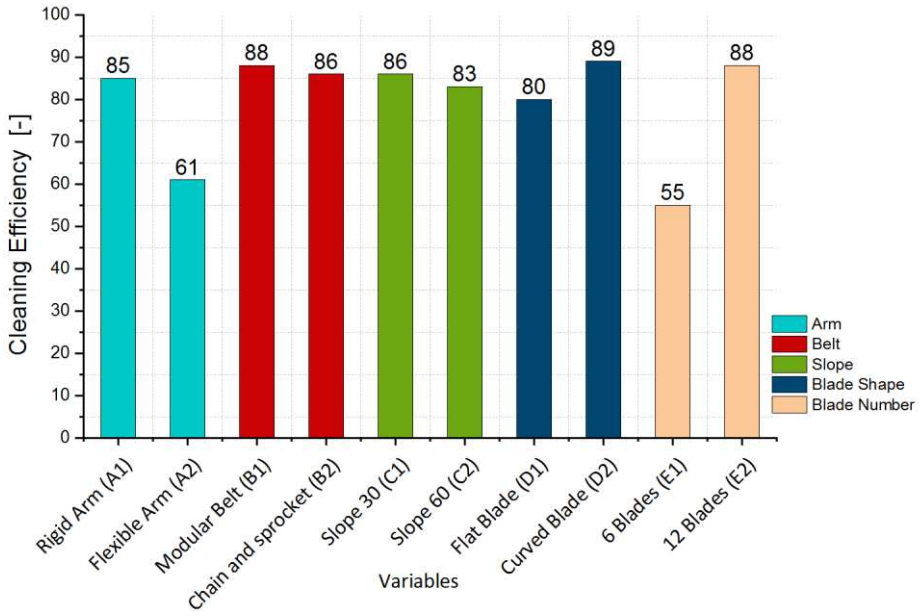


Fig .15 Individual efficiency of each variable (number of successfully collected residues out of 20 released)

The results obtained for the device variables indicated that the optimal configuration consists of a rigid arm assembly combined with a modular belt at an inclination angle of 30°, and 12 curved blades. As observed from the results, the flexible arm and the 6-blade configuration exhibited a negligible effect on the device performance. Furthermore, only minor differences were found among the variables of inclination angle, conveyor belt type, and blade shape, as shown in Fig. 15.

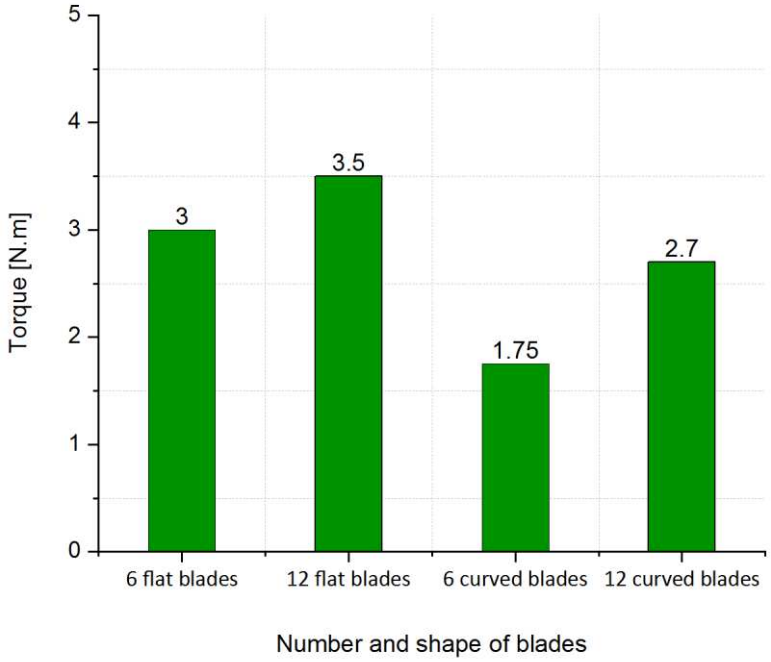


Fig .16 The torque of the rotating wheel at a river flow velocity of 0.4 m/s

The key influencing factors for the blade type and number parameters are torque and rotational speed. According to the obtained data Fig. 16, the maximum torque was observed for the flat blade configuration, with a value of 3.5 N·m, while the minimum torque corresponded to the curved blade with six blades, at 1.75 N·m. The torque value has a direct effect on the volume of residue that can be transported by the conveyor belt. As the residue volume increases, the torque applied to the rotating wheel also increases due to the greater load.

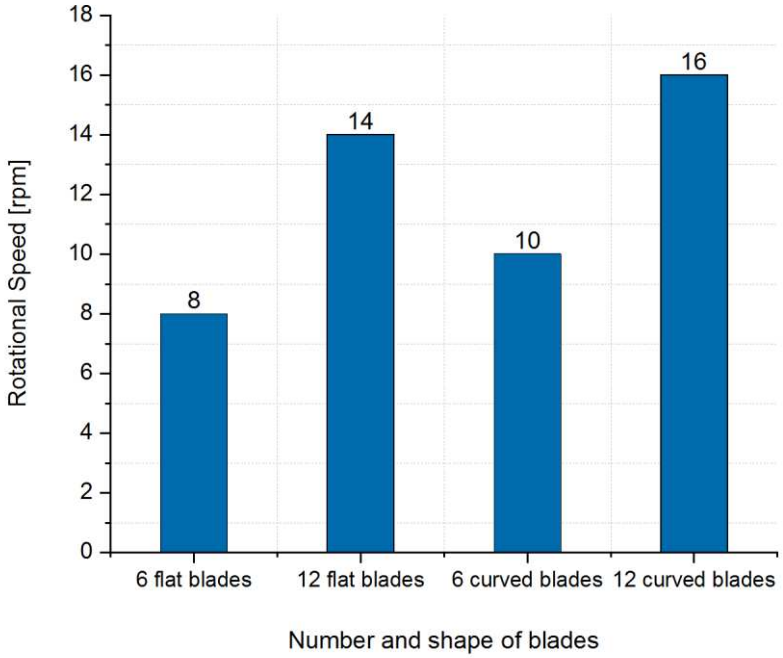


Fig .17 Rotational speed of the rotating wheel at a flow velocity of 0.4 m/s

Rotational speed also has a positive effect on the rotation of the rotating wheel and the conveyor belt, thereby increasing the amount of residue transported to the collection tank per unit time. As shown in Fig. 17, the highest rotational speed was obtained for the curved blades with 12 blades, reaching 16 rpm, while the lowest value was observed for the configuration with six flat blades, at 8 rpm, under a river flow velocity of 0.4 m/s.

Although a comparison between the two blade-shape configurations indicates superior performance for the curved blade, the higher torque associated with the flat blade, together with the relatively low importance of time as a performance criterion and the simpler fabrication and assembly process, suggests that the flat blade configuration can also be considered a suitable option for the device.

At this stage, the optimized prototype was evaluated at flow velocities of 0.4, 0.7, and 1.1 m/s using residue conditions comparable to real samples (Table 1) and in agreement with [13].

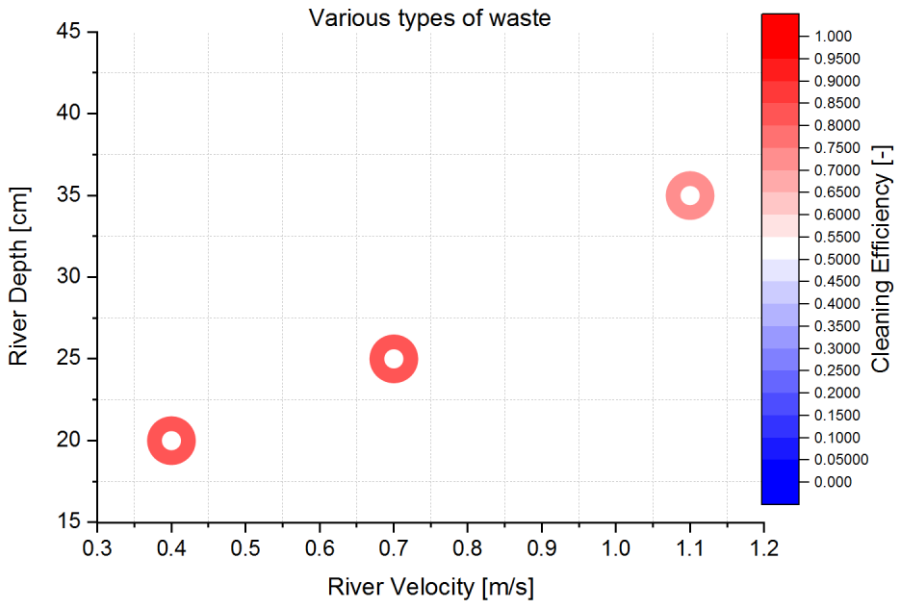


Fig. 18 Cleaning efficiency for Various Types of Waste (Table 1)

As shown in Fig.18, with five repetitions for each test, the average device efficiency was 83% (±2.74) at a flow velocity of 0.4 m/s, while efficiencies of 79% (±2.24) and 71% (±2.24) were obtained at flow velocities of 0.7 and 1.1 m/s, respectively. The standard deviation (SD) values in all three conditions are relatively small, indicating low data dispersion and, consequently, good repeatability and high reliability of the experimental results. These

results indicate that an increase in river flow velocity leads to a reduction in device efficiency, primarily due to the passage of residues beyond the effective range of the rigid arm and their failure to be transferred onto the conveyor belt.

The selected residues, in accordance with study [13], were released from a fixed distance upstream of the device following the same experimental procedure over five repetitions, and the percentage of collected residues was recorded. The results obtained for each type of wastes are presented in Figures 19–22. The variables considered in this experiment included river flow velocity, flow depth, and residue type, and the circles show the efficiency for wastes via the same color scaling.

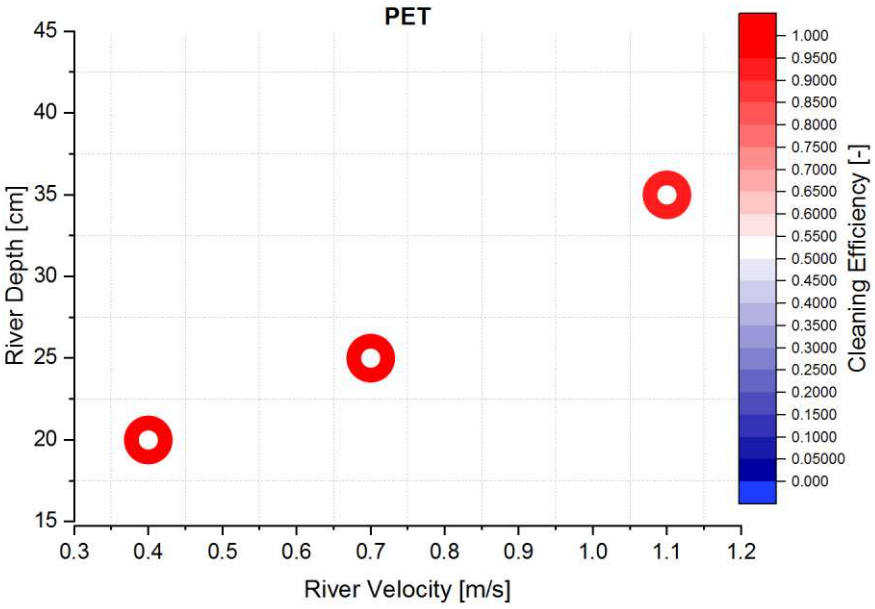


Fig. 19 Cleaning efficiency for PET waste at a specific river velocity and depth

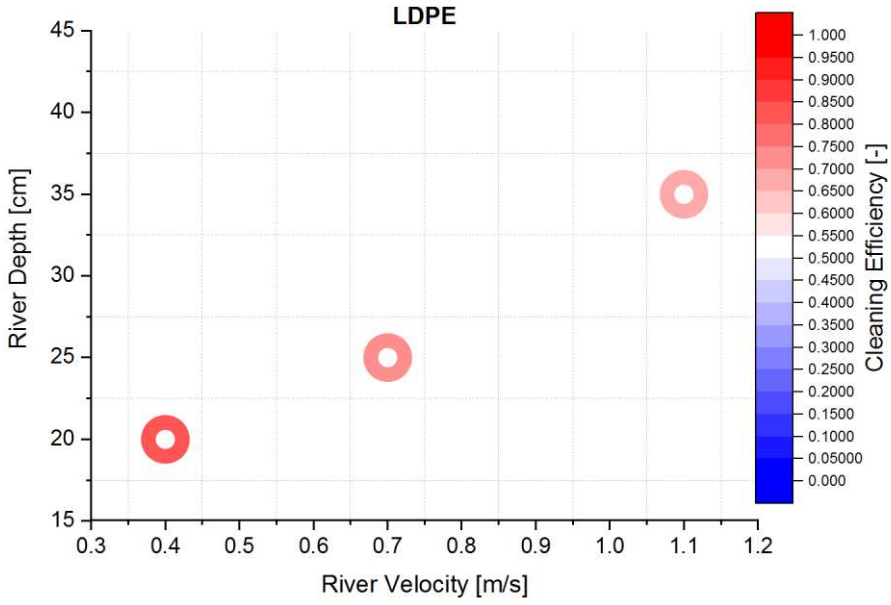


Fig. 20 Cleaning efficiency for LDPE waste at a specific river velocity and depth

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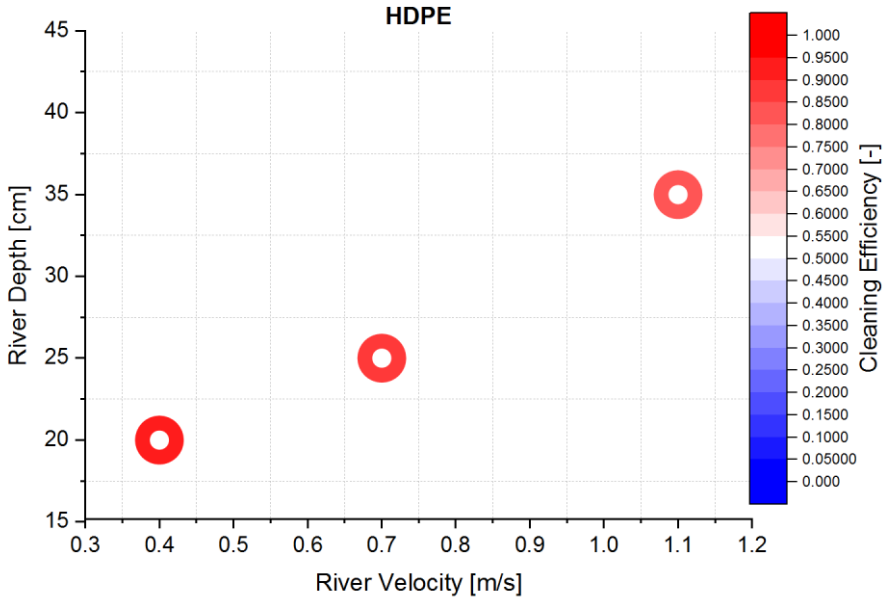


Fig. 21 Cleaning efficiency for HDPE waste at a specific river velocity and depth

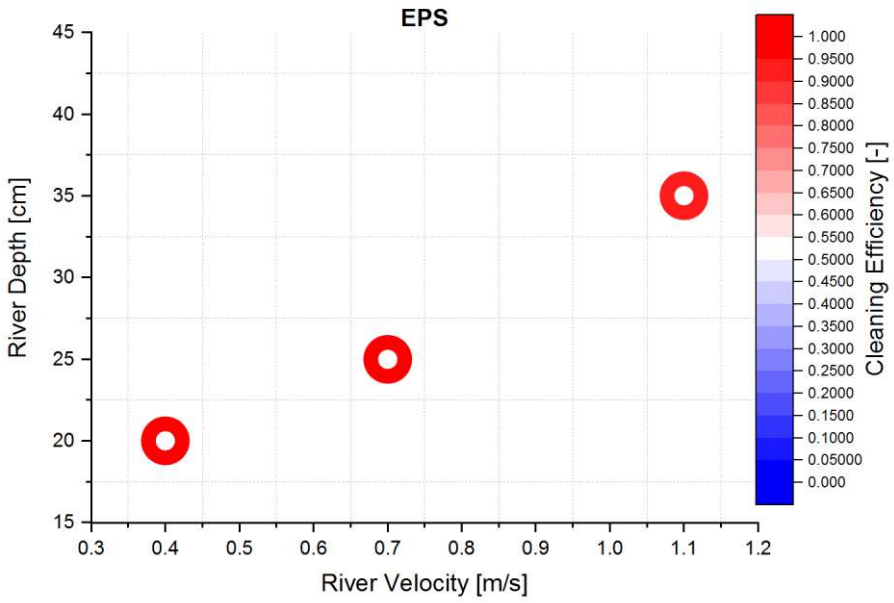


Fig. 22 Cleaning efficiency for EPS waste at a specific river velocity and depth

These data clearly demonstrate the combined influence of waste type and hydraulic conditions on the device efficiency, and enable analysis of the different behaviors of plastic materials under river flow conditions. Overall, a clear trend is observed across all materials: as the river flow velocity increases, the device efficiency decreases. This trend is consistently repeated for all four waste types, indicating that higher flow energy and increased hydrodynamic turbulence reduce the device's ability to guide particles toward the collection section.

At a flow velocity of 0.4 m/s, the efficiency reaches 100% for PET and EPS, indicating highly favorable conditions for system performance under low-flow regimes. Under the same conditions, HDPE also shows a very high efficiency of 93%, whereas LDPE exhibits the lowest performance among the four materials at 84%. This initial difference suggests that physical properties such as density and geometric characteristics play a decisive role in collection efficiency.

With an increase in flow velocity to 0.7 m/s, a reduction in efficiency is observed for all materials. PET and EPS still maintain very high performance (98%), while HDPE decreases to 90% and LDPE to 78%. This stage indicates the onset of stronger hydrodynamic effects and a higher probability of waste bypassing the effective capture zone of the device.

At the highest flow velocity (1.1 m/s), efficiency further decreases for all materials. PET and EPS maintain relatively high efficiencies of 91% and 90%, respectively, whereas HDPE and LDPE drop to 81% and 70%, respectively. These results indicate that under high-flow conditions, differences in material behavior become more pronounced, and the influence of waste physical properties on flow–structure interaction becomes more evident. PET and EPS, due to better buoyancy characteristics and more stable hydrodynamic behavior, show greater resistance to bypassing the system, whereas LDPE experiences the highest efficiency reduction due to its less predictable geometrical behavior during transport.

4. Discusstion

The results of this study demonstrated that the performance of the designed floating waste collection system is directly influenced by the mechanical properties of its components and the hydraulic flow conditions. A separate analysis of the design variables showed that the combination of a rigid arm, modular belt, 30° installation angle, and 12 curved blades achieved the highest waste collection efficiency.

The poor performance of the flexible arm can be attributed to its instability under flow-induced forces and its reduced ability to guide waste toward the conveyor belt, which is related to the high density of the rubber component used in its structure. In contrast, the rigid arm exhibited significantly better performance due to its improved buoyancy and stability at the water surface, enabling more effective guidance of waste toward the device intake.

Regarding the conveyor belt installation angle, the results indicated that a 30° inclination outperformed a 60° configuration. This is likely because the 30° angle provides an optimal balance between the force required for waste transport and the stability of particle movement along the belt surface.

The type of conveyor belt also influenced the system's performance, although the observed differences among the tested configurations were relatively limited. The modular belt demonstrated superior performance compared to the other belt types due to its segmented structure, more favorable friction characteristics, and greater stability in contact with the collected waste. In addition to providing more effective waste transport, this belt type also showed improved resistance under wet conditions and continuous exposure to water, while allowing for simpler maintenance, as individual segments can be repaired or replaced easily.

In contrast, the chain-and-sprocket configuration, owing to its smoother surface and higher tendency for slippage, occasionally resulted in reduced control over waste movement. Although the differences in overall efficiency among belt types were not substantial, the operational and maintenance advantages of the modular belt justify its selection for the proposed system.

The number of blades had a direct influence on the rotational speed and torque of the rotating wheel, thereby enhancing the overall system performance. The results for torque and rotational speed indicated an inverse relationship between these two parameters. Flat blades generated the highest torque, reflecting their greater capability to withstand and transmit higher waste loads.

However, curved blades achieved higher rotational speeds, which led to an increased number of waste transfer events per unit time. Accordingly, although curved blades demonstrated superior overall efficiency, flat blades can also be considered a viable option for practical applications due to their simpler manufacturing process, higher structural strength, and greater torque generation capacity.

These findings indicate that the final design selection may vary depending on operational priorities, including efficiency, manufacturing cost, and maintenance requirements.

Evaluation of the optimal prototype at different river flow velocities showed that increasing flow velocity leads to a reduction in device efficiency. The average efficiency decreased from 83% at a flow velocity of 0.4 m/s to 71% at a flow velocity of 1.1 m/s.

The main reasons for this trend can be attributed to increased flow energy, higher turbulence, and the low elevation of the rigid arm. At higher velocities, a portion of the waste passes alongside the device before reaching the conveyor belt, resulting in a loss of collection opportunity.

These findings are consistent with the typical behavior of mechanical waste collection systems in riverine environments, where increasing flow velocity generally reduces guidance accuracy and collection performance [13].

An evaluation of waste types also demonstrated that the physical properties of the materials play a significant role in system efficiency. PET and EPS waste showed better performance than LDPE and HDPE across all flow velocities, with even 100% efficiency recorded at low velocities. This is likely due to the greater stability of these materials at the water surface and their more favorable hydrodynamic behavior when exposed to flow conditions.

In contrast, LDPE exhibited the lowest efficiency, which may be attributed to its low weight, high flexibility, and irregular motion on the water surface. These characteristics increase the likelihood of waste bypassing the effective capture zone of the device.

At higher flow velocities, differences in material performance became more pronounced, indicating the combined influence of waste type and flow intensity on system efficiency.

Overall, the results of this study indicate that the proposed system demonstrates a satisfactory capability for collecting floating waste from river surfaces and can operate with high efficiency under low to moderate flow conditions. However, the observed decline in performance at higher flow velocities highlights the need for further optimization of the guiding components and an increase in the collection coverage area under more severe hydraulic conditions.

This study also shows that, in the design of riverine waste collection systems, simultaneous consideration of the device's mechanical parameters, flow conditions, and the physical properties of the waste is essential to achieve maximum efficiency.

Although several plastic pollution collection devices are already on the market and in operation in the form of booms (floating barriers), watercraft vehicles, or receptacles, there is a need for more information on efficiency and capacity. Helinski et al. could only gather information on efficiency for 27.5% of their examined concepts [24].

Comparison of these technologies is also challenging due to differences in efficiency definitions and performance metrics (reported either as percentages [%] or kilograms per day [kg/day]), the lack of standardized and peer-reviewed methodologies, variations in technology readiness levels (TRL), differences in application sites, and differences in target loads [24]. In addition, current monitoring methods are associated with considerable uncertainties, such that even recent estimates of plastic loads in rivers exhibit low accuracy and tend to underestimate suspended plastic loads [25]

Technical solutions to capture floatables, such as StormTrap's "TrashTrap: Capture floatables with innovative netting systems: Trash Removal Solutions for Stormwater, Urban Runoff and Combined Sewer Overflow (CSO) Discharges" or the "River Cleaning System: consisting of floatable devices", report removal efficiencies of 97% and 85%, respectively [13].

With all the above considerations, the selection of waste in this study was carried out in a way that allows the performance of the device to be compared with the results reported for the "TrashTrap system" and the "River Cleaning System" using the waste types shown in Table 1, as well as with the findings of study [13] regarding polymer waste. Although identifying a fully comparable study was challenging, efforts were made to ensure that the environmental and experimental conditions were as closely matched as possible.

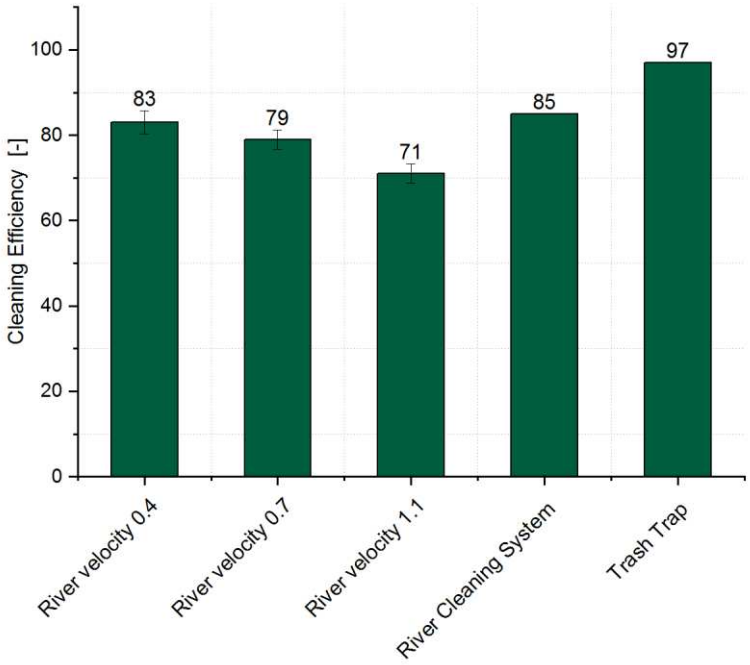


Fig .23 Comparison of cleaning efficiency for various types of waste (Table 1)

As shown in Fig.23, the performance of the proposed system in this study shows only minor differences compared to the StormTrap TrashTrap and the River Cleaning System; however, it should be noted that the underlying operational mechanisms and hydromechanical principles of these systems are not identical.

These findings can be interpreted as part of the validation process of the proposed device, demonstrating that, despite conceptual differences in the collection mechanisms, the developed system is capable of operating within a comparable performance range to existing technologies.

In study [13] , waste experiments were conducted under fully controlled conditions, where flow velocities were set at 0.2, 0.6, and 0.8 m/s at a constant flow depth of 40 cm, as well as at velocities of 0.2 and 0.4 m/s at a flow depth of 80 cm. In other words, the hydraulic parameters were strictly controlled and maintained constant throughout the experiments. In contrast, the present study was carried out in a natural riverbed environment, where flow velocity and water depth could not be controlled. Measurements were performed at different times of the year, and the results were reported according to the prevailing field conditions. Under these circumstances, the river depth varied as a function of flow velocity; specifically, the measured depths were 20 cm at a velocity of 0.4 m/s, 25 cm at 0.7 m/s, and 35 cm at 1.1 m/s. The results obtained in this study and those reported in study [13] are presented comparatively in Figures 24–27.

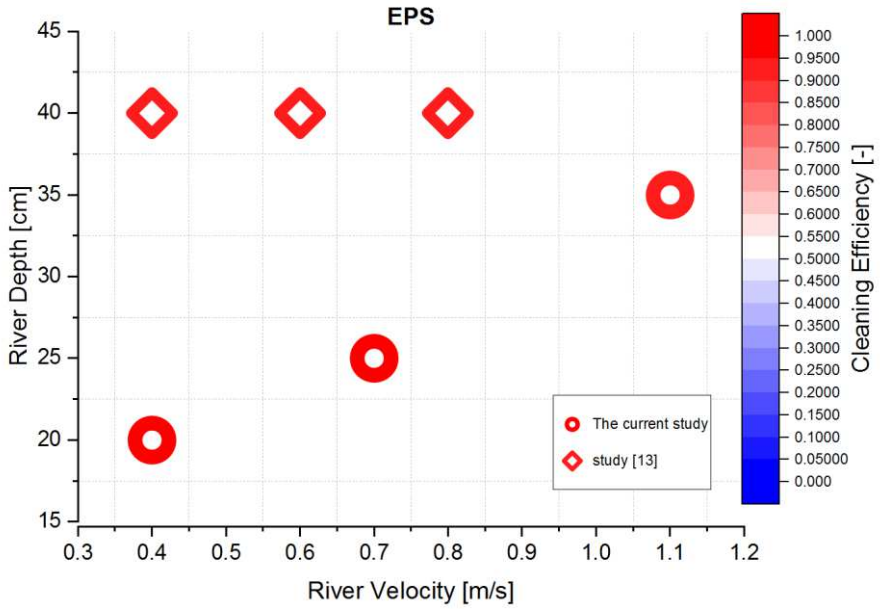


Fig. 24 Comparison of cleaning efficiency for EPS waste

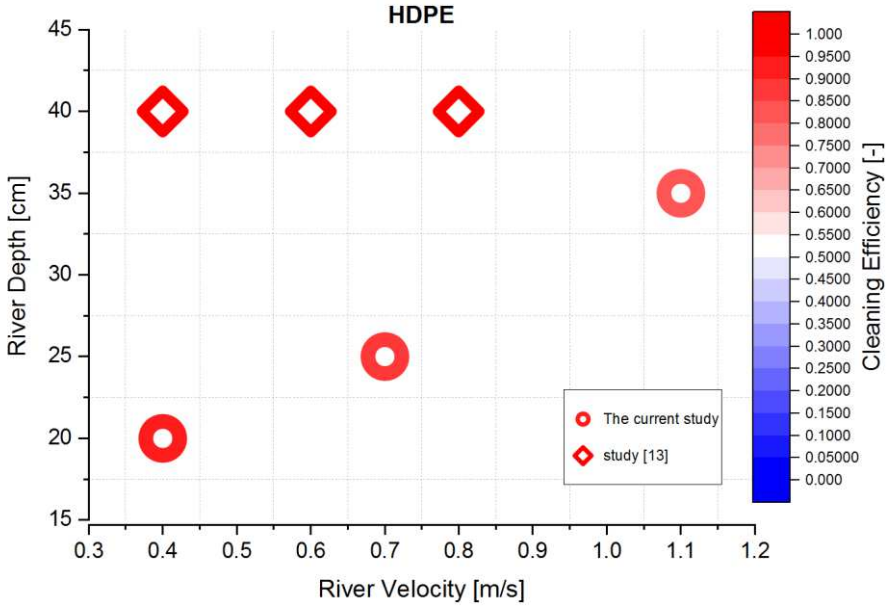


Fig. 25 Comparison of cleaning efficiency for HDPS waste

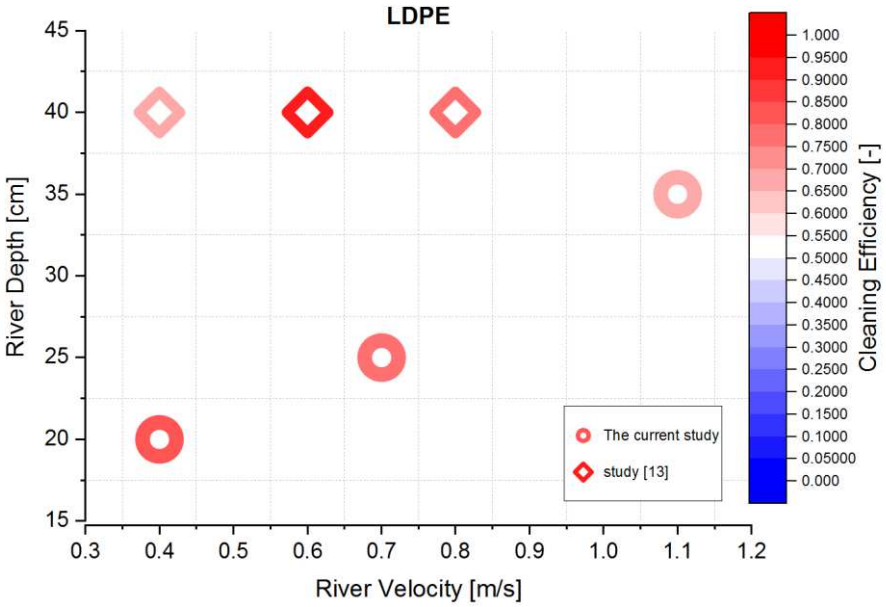


Fig. 26 Comparison of cleaning efficiency for LDPE waste

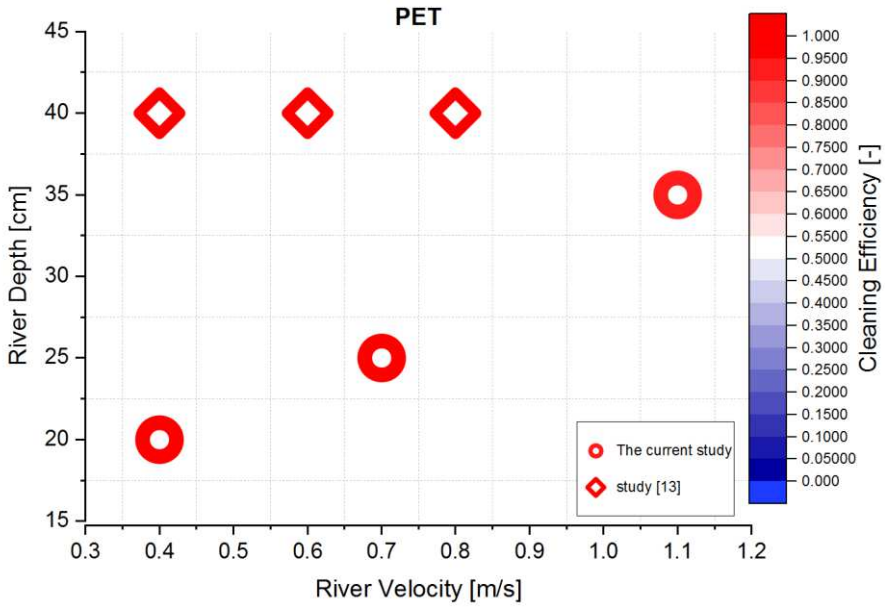


Fig. 27 Comparison of cleaning efficiency for PET waste

Despite differences in hydraulic conditions and system design, both devices showed comparable collection performance for three dimensional polymer waste.

For PET and EPS, efficiencies remained consistently high (90–100%) across all flow conditions, indicating strong buoyancy driven capture performance.

For HDPE, efficiency in the present study decreased with increasing flow velocity (93% to 81%), whereas Study [13] reported consistently higher values (92–100%) under controlled hydraulic conditions, likely due to improved capture of floating and partially suspended waste.

For LDPE, both systems exhibited lower and flow dependent efficiencies (70–90%).

Overall, the comparison indicates that although the device used in Study [13], due to its mechanical design optimized for floating and suspended waste, performs better when handling materials with densities close to or higher than that of water, its efficiency for fully buoyant waste is very similar to that observed in the present study. This finding confirms the satisfactory performance of the device evaluated in this research.

5. Conclusion

This study presented the design, fabrication, and experimental evaluation of a laboratory-scale hydromechanical floating waste collector powered exclusively by river flow energy. Unlike conventional river-cleaning systems that depend on external electrical or fossil-fuel-based power sources, the proposed device demonstrated the feasibility of continuous waste collection through direct utilization of hydraulic kinetic energy, providing an energy-autonomous and infrastructure-independent solution for riverine waste management.

The experimental results revealed that the overall performance of the system was strongly affected by the interaction between hydraulic conditions, mechanical configuration, and waste characteristics. Among the investigated design variables, the configuration consisting of a rigid guiding arm, modular conveyor belt, 30° conveyor inclination angle, and 12 curved blades achieved the highest collection efficiency of 83% under low flow conditions. Increasing the number of blades improved rotational stability and waste transfer continuity, while curved blades enhanced rotational speed and collection frequency. In contrast, higher conveyor inclination angles reduced the transport efficiency of lightweight and irregularly shaped waste materials.

The study further demonstrated that flow velocity plays a critical role in system performance. Collection efficiency decreased with increasing river velocity due to intensified turbulence and reduced guidance capability near the conveyor inlet. Nevertheless, the device maintained satisfactory performance under moderate flow conditions, particularly for highly buoyant materials such as PET and EPS, which achieved efficiencies exceeding 90% in most experimental scenarios.

Comparison with previously reported river-cleaning technologies indicated that the proposed system operates within a comparable efficiency range despite relying solely on hydromechanical power generation. This finding highlights the potential of self-powered river cleaning technologies as sustainable alternatives for floating waste interception in remote or energy-limited environments.

From a waste management perspective, the proposed system contributes to reducing uncontrolled transport of plastic debris from rivers to marine ecosystems and supports sustainable recovery of floating recyclable materials before environmental dispersion. The absence of external energy demand may also reduce operational costs and improve long-term deployment feasibility in developing regions and small-scale waterways.

Although the present prototype demonstrated promising performance, several limitations remain. The system efficiency decreased under high-flow conditions, and the guiding mechanism requires further optimization to improve waste interception under turbulent hydraulic regimes. Future studies should therefore focus on scaling analysis, long-term field deployment, hydrodynamic optimization of the guiding arms and blade geometry, and integration of automated waste monitoring systems. In addition, evaluation under seasonal flow variations and larger river widths is recommended to assess full-scale operational applicability.

Overall, the findings confirm that river flow driven hydromechanical systems can provide an effective, low energy, and environmentally sustainable approach for continuous floating waste collection in natural waterways, thereby contributing to global efforts toward plastic pollution mitigation and circular waste management.

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