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High-Speed Descent and Low-Speed Ascent: A Novel Gravity–Buoyancy Hybrid System for Sustainable Power Generation

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Abstract

Modern renewable power systems often face challenges in achieving continuous output and low cost per kWh. This study introduces a gravity–buoyancy hybrid energy system that leverages hydro-mechanical interactions to provide baseload-capable, self-sustain electricity generation. By combining high-velocity gravitational descent of dense payloads with low-velocity buoyant ascent in a closed-loop architecture, the system achieves continuous mechanical-to-electrical conversion. Unlike perpetual motion fallacies, it adheres to thermodynamic laws, deriving output from gravitational potential replenished via efficient hydrostatic mechanisms. The design emphasises modularity, economic scalability, and environmental compatibility, aligning with United Nations Sustainable Development Goal 7 (Affordable and Clean Energy). Theoretical analysis shows a net mechanical-to-electrical conversion efficiency approaching 90%, with per-column output of ~0.5 MW. Cost assessment yields ₹0.652/kWh with a payback period of 3.67 years for a 100 MW plant, outperforming conventional renewables in cost and continuity.

Keywords: gravitational kinetic energy; buoyancy power; hydro-mechanical system; renewable baseload; energy conversion; sustainable power; green energy.

Highlights

- Introduces a closed-loop **gravity–buoyancy hybrid system** for continuous power generation.
- Achieves **0.5–0.67 MW output per column** with over **90% mechanical efficiency**.
- Utilises hydrostatic equilibrium and kinetic synchronisation to minimise energy loss.
- Provides **terrain-independent, modular, and scalable** renewable energy infrastructure.
- Demonstrates **low LCOE (₹0.652/kWh)** and **long service life (≈60 years)** for baseload supply.

1. Introduction

Modern renewable systems, such as solar and wind, remain intermittent, requiring costly storage or backup systems to deliver steady baseload power. Existing gravity storage technologies, such as pumped hydro and solid-mass lifting systems, offer partial solutions but remain limited by **terrain dependency** and **auxiliary energy needs**. This paper proposes a **gravity–buoyancy hybrid energy system** capable of self-sustaining operation within thermodynamic limits. It integrates gravitational potential and buoyant recovery phases in a **shared-wall, closed-loop**

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hydro-mechanical column, delivering continuous rotation for power generation. The study aligns with the goals of **green technology**, emphasising a long lifecycle, minimal environmental disturbance, and scalable modularity suitable for inland installations.

2. Prior Art Review

Gravity energy systems evolved from classical **pumped-hydro plants** (70–85% efficiency) to modular innovations like **Gravity Power's underground piston** or **Energy Vault's block-stacking cranes**, achieving 80–90% efficiency but at high land and material cost (1). Buoyancy-based systems, such as submerged air chambers or ocean-floater designs, harness upward forces but require significant input energy for submersion. Previous hybrid concepts suffered from synchronisation losses between mechanical and hydrostatic phases, producing frictional and drag inefficiencies. This work distinguishes itself by integrating:

- **High-speed gravitational descent** (4 m/s),
- **Low-speed buoyant ascent** (0.8 m/s), and
- **Hydrostatic equivalence mechanisms** that eliminate the need for pumps.

No prior design has combined these dynamics in a **shared-wall, modular J-shaped water column**, achieving efficient continuous conversion.

3. Unmet Needs

Existing renewable technologies exhibit:

- Terrain dependency (hydro reservoirs).
- High CAPEX (dam excavation or tower construction).
- Limited continuous operation due to loss of kinetic phases.

A **self-contained, modular, terrain-independent system** capable of generating ~0.67 MW per column with <10% auxiliary energy and <₹1/kWh generation cost remains technologically unaddressed.

Background:

Modern renewable power systems often face challenges in achieving continuous output and low cost per kWh. This study introduces a gravity–buoyancy hybrid energy system that leverages hydro-mechanical interactions to provide baseload-capable, self-sustaining electricity generation. This paper presents a novel gravity–buoyancy hybrid energy system. By combining high-velocity gravitational descent of dense payloads with low-velocity buoyant ascent in a closed-loop architecture, the system achieves continuous mechanical-to-electrical conversion. Unlike perpetual motion fallacies, it adheres to thermodynamic laws, deriving output from gravitational potential replenished via efficient hydrostatic mechanisms. The design emphasises modularity, economic scalability, and environmental compatibility, aligning with United Nations Sustainable Development Goal 7 (Affordable and Clean Energy).

4. **Materials and Methods**

4.1 System Architecture-The power generation system involves cylindrical steel buckets, half open and half-closed, having a mass of 100 kg, designed to float (Figure 1) and a circular metal block, mass 860 kg of mild steel with zinc coating (Figure 2) for loading in the upper portion of the empty buckets (2). One J- shaped cemented empty column having a lower end 1.5 meters high and an upper end 100 meters high, and a base width of 20 meters and a base length of 10 meters for the upper end, with a 10-meter lower end, filled with water (Figure 3). The roof of the lower end is curved upward toward the upper end at a 30-degree angle (1). All such 200 water columns are arranged in two rows sharing one side wall and one back wall to reduce construction volume (1). This structure uses 2000 x 40 square meters or 20-acre land for 100 MW net power (Figure 4). 1067 empty buckets float by buoyancy with 0.8 m/s up-speed in water at different heights in about 133 rows, having 8 buckets in one row and a gap of 0.25 meters, reach the top of the water column, and collect in a circular reservoir (Figure 5, the complete assembly drawing of one unit). The reservoir at the column's top holds 30 partially submerged, bottom-up empty buckets circulating in a loop between two steel rods. Eight buckets exit and eight enter the reservoir per second, maintaining a constant count. Floating buckets (2) strike on a conical bottom shape, A B C, and are directed towards the periphery of two round circular rods (Figure 6). From the reservoir, at one location in the path, buckets move to Channel-7, an inclined conveyor that lifts them above water to drain residual liquid and forwards them to vertical robotic arms.

The vertical robotic arm (Figure 7A) has multiple arms for gripping each empty bucket from the sides of the top of channel 7 and rotating them from a bottom-up to a bottom-down orientation, placing them onto an 85-meter-high stack of empty buckets in a vertical pipe at an 8 buckets per second rate. Channel-7 is 0.2 meters narrower than the bucket diameter to support this mechanism. For working robotic arms (4) mechanically without electronics, a pulling spring is fixed between each pair of opposite arms of the wheel (4). A curved plate is also fixed externally between arms in such a way that when the arms leave the plate, the spring pulls the opposite arms to grip the buckets. When arms strike the plate, then increase the distance between opposite arms to leave buckets (Figure 7 B). An 85-meter vertical pipe, positioned 15 meters above ground and parallel to the water column, holds 170 stacked empty buckets (0.5 meters each). Bearings (3) on the pipe's inner surface reduce friction and ensure alignment, with the lowest bucket supporting the stack's weight. Bearings are fixed on an external plate that enters the pipe with a cut in the wall of the pipe, enabling the change of a single bearing if needed (Figures 5 and 8). The entire load of these 170 empty buckets passes over two rim pulleys, descending at a speed of 4 meters per second without slipping (4). The rotating rim pulleys are connected to a generator, transferring mechanical energy for power generation. After passing the rim pulleys, the empty buckets are placed onto a horizontal track, Channel-8, that moves buckets at 6 m/s speed (Figure 5). To extend the filing time (~3 seconds per bucket), buckets are transferred from Channel-8 to a horizontal circular disk (Figure 9), where 24 buckets are filled simultaneously with 860 kg of metal blocks using a central filling arm. The tangential speed of the disk is 6 m/s at which loaded buckets exit from the disk using centrifugal force. An open-ended railing having a bearing is fixed around a horizontal disk to prevent buckets from exiting before the desired location. The rotational motion of the disk is provided by a 2-kW servo motor, which ensures precise speed and torque control during operation. If the horizontal disk is not used, then extend channel-8 length to fill blocks in buckets and deliver to the next water column entry gate. In total, eight empty buckets enter per second on disk and eight loaded buckets per second exit from the disk or channel-8 (Figure 5). Buckets exit from horizontal disk or from extended channel-8 are gripped at the sides by another vertical rotating arm (Figure 10) fitted with rotating fingers which convert the horizontal motion of the heavy bucket into a downward inclined path while securely holding the loose block in place. Here, arms do not hold the weight of the loaded bucket but immediately push down the bucket, keeping a small tilting upper side to smoothly place the buckets on the gate stack (Figure 5).

The inclined gate-stack assembly comprises a 30° inclined arrangement of 44 buckets positioned along an inclined channel connecting the lower end of the water column to the horizontal disk. At the roof of the lower end, an entry gate integrated with a circular regulating valve controls the transfer of loaded buckets from the gate stack into the water column at a uniform rate of eight buckets per second. Upon entry, each bucket impacts the belt of a pushing pulley at an incidence angle of approximately 30°, initiating its submerged motion. The pushing pulley, located directly beneath the entry gate, forms part of a conveyor belt mechanism wherein the primary pulley operates at a fixed position, while the secondary pulley performs a reciprocating horizontal motion. This coordinated movement directs successive sets of eight buckets alternately along horizontal paths within an area of approximately 20 × 10 m^2. During this motion, the buckets gradually decelerate and invert as their lower compartments are emptied. Subsequently, the metallic blocks are released, rendering the buckets buoyant and allowing them to ascend through the water column by the action of buoyancy (Figure 5). Pushing the pulley pushes the buckets with a curved face, using 16 kW of power. The flexible rubber valve (Figure 11) in the gate has increasing thickness from the lower end to the upper end in a round pipe form. Only the lower end of the valve touches the cylindrical buckets. Water pushes the flexible valve, and the valve presses the cylindrical bucket. Since no space exists between the valve and the buckets, no water leakage is possible. This is perfect even in a small vibration in the bucket's motion. Metallic blocks, delivered via buckets, descend towards the bottom and are placed on a base-mounted rotating plate (Figure 12A). The plate directs blocks uniformly toward the circular flexible valve in the wall of the water column, and two wheels at the valve align and push the block in the valve (Figure 12B).

Outside the circular valve, 53 blocks form a 60-degree inclined stack on a smooth bearing (3), fixed to two rail lines with a vertical height of 13 meters and an inclined length of 15 meters. Since the metallic block has a density of 7800 kg per cubic meter and water density is 1000 kg per cubic meter, then the 100-meter water pressure balance block's height (100 x 1000)/7800 =13 meters.

Meaning, the 13-meter block's weight is equal to 100-meter water weight. If one block exits from this inclined stack, then one new block enters the valve, and water pressure pushes the stack upward (Figure 13). From this 13-meter height, an industrial bucket elevator lifts a block 1.5 meters high to place onto empty buckets on a horizontal disk at a rate of 8 blocks per second (Figure 14).

4.2-: To synchronise the process, all rotating parts like the rim pulleys, horizontal disk (12), rotating robotic arms and gate stack channel are coupled by a gear system. 44 blocks in a 30-degree inclined plane at the gate is equal to 22 blocks in a vertical stack. The system claims to sustain this process with only 22 loaded buckets in the vertical gate stack, leveraging kinetic energy at 4 m/s while inserting 8 buckets per second into the water (Figure 5). Using a synchronised mechanical assembly of robotic arms, pulleys, and valves, eight loaded buckets enter the column per second, while an equal number of empty buckets float upward by buoyancy. The "high-speed descent and low-speed ascent" mechanism distributes buoyant work across smaller, slower-moving buckets, reducing the total insertion energy while maintaining throughput.

5. Theoretical Analysis and Energy Balance

5.1 Bucket Specifications---

Empty bucket mass: 100 kg. Height = 0.5-meter, diameter = 0.75 meter
Bucket cross-section area (A) = $\pi r^2 \approx 0.4418 \text{ m}^2$
Volume of bucket = A x h = 0.4418 x 0.5 = 0.2209 meter^3

5.2 Circular Block Specification---

Density of metal block = 7800 kg/meter^3
Mass of one block = 860 kg, diameter 0.7-meter and height 0.28 meter
Total mass each loaded bucket (bucket + block) = 100 + 860 = 960 kg
Density of block filled bucket = 7800/2 = 3900 Kg/meter^3

5.3 Entry Gate Pressure: (20)

Dynamic pressure will be ½ x density x v^2
= ½ x 3900 x 4 x 4 = 31200 Pascal
Static pressure =1000 x 9.8 x 98.5 = 965300 Pascal
Total water pressure on gate = 965300 + 31200 = 996500 Pascal
then water thrust on gate = bucket bottom area x water pressure= 0.4418 x 996500 = 440254 Newton

5.4 Gate-Stack Specifications

Vertical component of 44 buckets inclined at 30 degrees is equal to 44 sine 30 = 44 (1/2) = 22.
Number of buckets in stack =22
Total stack mass = 22 x 960 = 21120 kg
Stack speed = 4 m/s downward
Entry rate = 8 buckets per second.

Volume enters in water = 8 x 0.2209 = 1.767 meter^3/sec

5.5 Forces at entry gate (14)

Upward water thrust force = pressure x bottom area of bucket
= 0.4418 x 996500 = 440254 Newton
Downward Force in the stack
Gravitational force from 22 buckets mg = 22 × 960 × 9.8 = 206976 N
Total kinetic energy of 22 loaded buckets at 4 m/s
= $1/2mv^2=1/2 \times (22\times960) \times 4^2$ = 168960 Joule
Force due to kinetic energy
= Kinetic energy / insertion depth per bucket = 168960 / 0.5 = 337920 Newton
Total force applied by 22 loaded buckets in stack = 206976 + 337920 = 544896 Newton
544896 Newton, which is greater than the force required for insertion, 440254 Newton. So, the force in the dynamic stack is greater than the thrust force on the stack, including valve pressure and frictions
It means insertion is easily possible (15).
Since this force is available each time a bucket enters—and the stack remains in uniform motion—it is not spread across multiple insertions but is effectively applied per insertion due to conservation of momentum and energy. This means neither the mass nor the velocity of the gate-stack is reduced. In a steady state, the gate-stack acts like a moving piston, delivering full kinetic energy with every bucket, and the bottom bucket transfers this energy into the water (16).

5.6 Insertion power: 996500 Pa × 1.767 m^3/s = 1.761 MW (split: 0.876 MW blocks lift, 0.837 MW buoyancy/kinetics)(drawing-15).

5.7 Output: 170 × 100 kg × 9.8 N/kg × 4 m/s = 0.67 MW (85-m drop; remainder recycles via 15-m phases).

Auxiliary: Pumping (67.4 kW) + feeds (2 kW) + misc. (~15 kW) = 0.069 MW. Net: ~90% efficiency, with buoyancy (0.078 MW) and kinetics augmenting output.

1,067 floating buckets, each with a buoyancy force in water of 98 N at 0.8 m/s, take 0.078 MW in lifting. The remaining ~0.807 MW from insertion (1.761 - 0.876 - 0.078) manifests as kinetic "pulling" effects: submerged buckets create voids, reducing effective stack height and drag via momentum conservation (Third Law dynamics at gate).

Friction is negligible (bearings, smooth surfaces); dynamic pulling reduces stack height, self-sustaining at >0.2 m/s.

Accounting for mechanical losses, net electrical output is ~0.5 MW per column.

6. Economic Feasibility and Scaling (18,19,20,21,22,23)

For a 100 MW system, CAPEX = ₹572 Cr, LCOE = ₹0.652/kWh, annual output = 788.4 million kWh, payback = 3.67 years. Compared to solar (₹2.3–3.0/kWh) and wind (₹2.8–3.2/kWh), this system offers lower cost, higher lifespan (60 years), and 24×7 operation--three to four times lower than solar or wind—using 20 acres of land for 100 MW.

7. Conclusions:

The gravity–buoyancy hybrid system offers a robust, continuous, and sustainable power generation method. By harmonising gravitational descent and buoyant ascent speeds, the design minimises input energy while maximising hydro-mechanical efficiency. With its scalable, low-tariff profile and long operational life, this technology presents a promising alternative to conventional renewables for inland and off-grid applications.

8. Discussion

The system demonstrates how controlled hydrostatic and mechanical synchronisation can yield **continuous, pump-free operation**. The balance between gravitational and buoyant forces ensures that each cycle replenishes potential energy efficiently.

Mechanical automation via **spring-based robotic arms** and **flexible valves** avoids electronic dependency, enhancing durability. Shared-wall civil architecture minimises material use.

Future work includes prototype validation, flow simulations, and multi-column synchronisation analysis to optimise efficiency under varying loads.

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Conceptualised as an original invention under the Indian Patent Act, figures derived from technical specifications.

Declaration of Interest Statement/Funding Sources:

The author declares that there are **no known competing financial interests or personal relationships** that could have appeared to influence the work reported in this paper. This research was conducted **independently and without external funding**, institutional affiliation, or commercial sponsorship.

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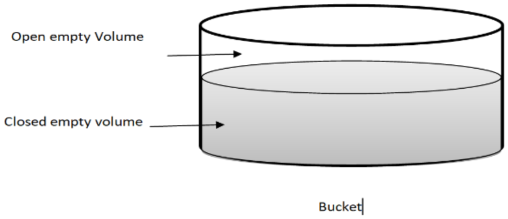
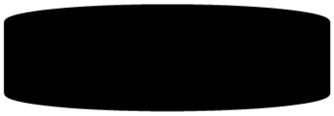


Figure-1



MILD STEEL SOLID CIRCULAR BLOCK, MASS 860 KG

Figure-2

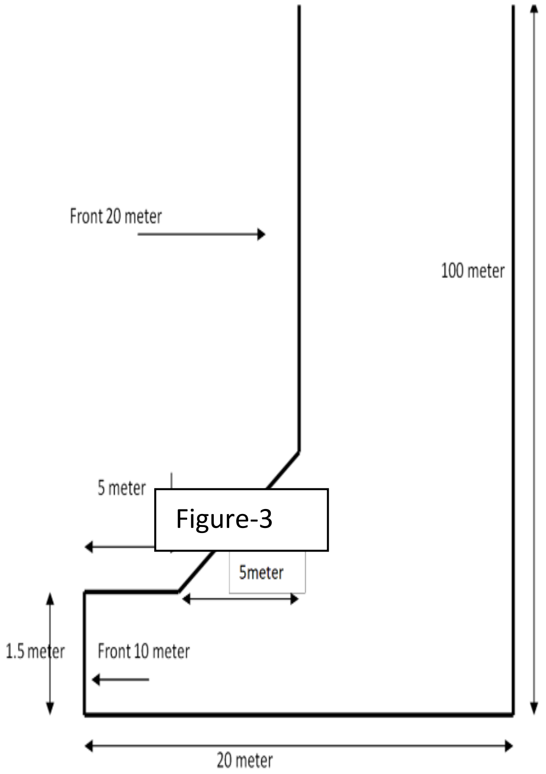


Figure-3

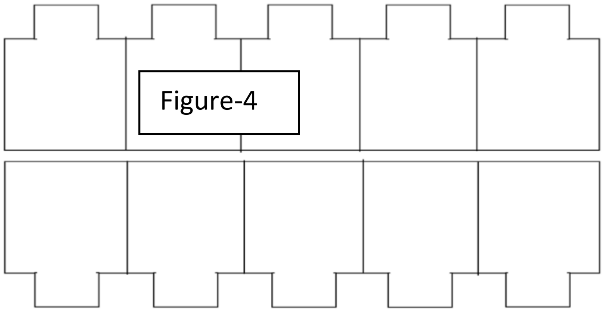


Figure-4

Foundation structure of water columns

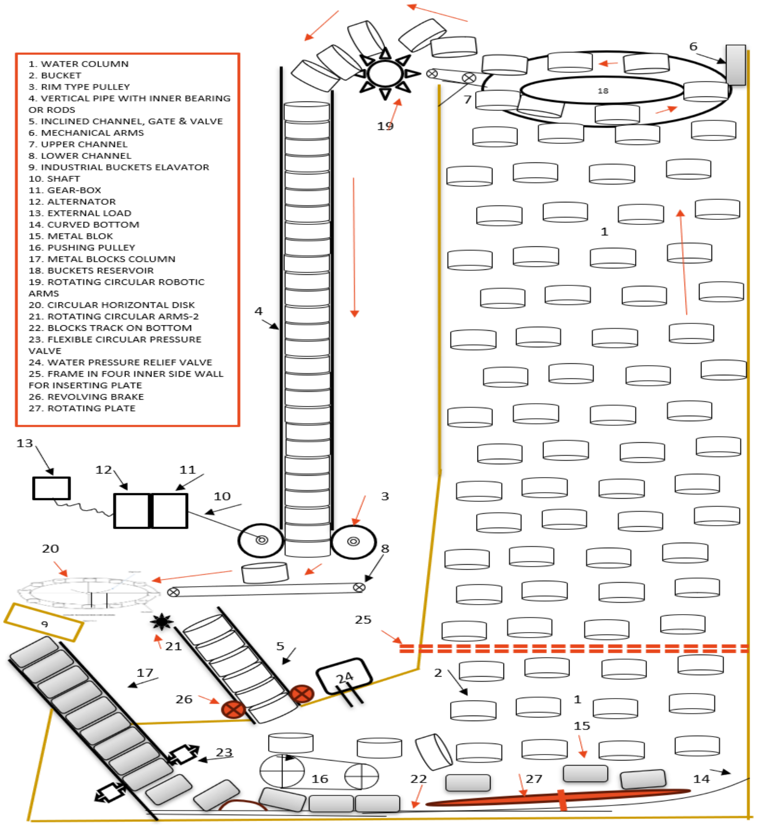


Figure-5

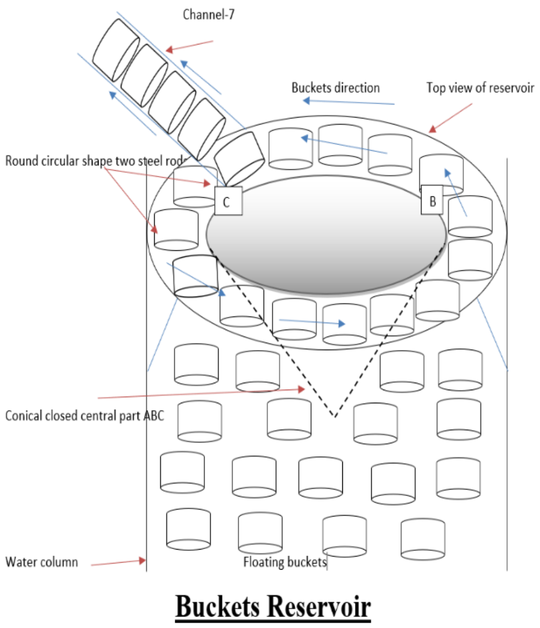
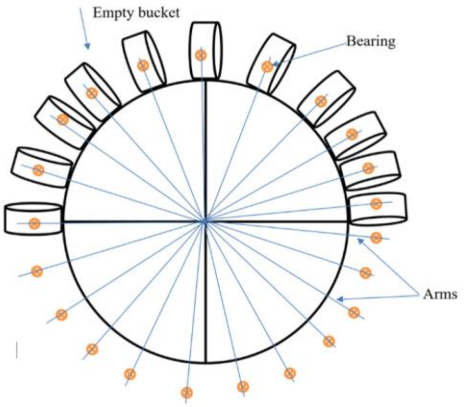


Figure-6



Rotating Circular Robotic Arms clipping buckets from sides

Figure-7A

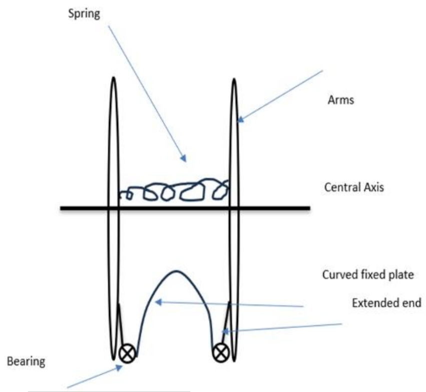


Figure-7B

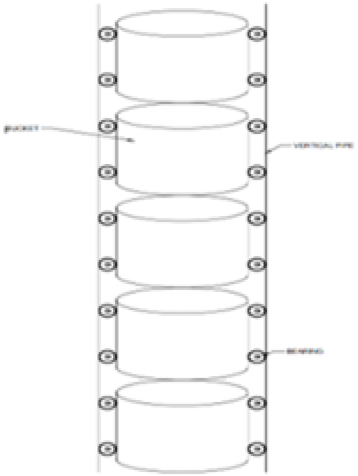
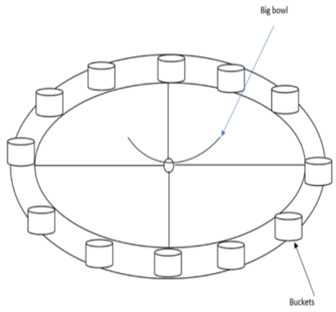
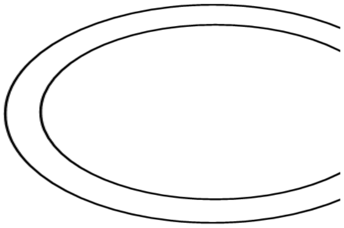


Figure-8



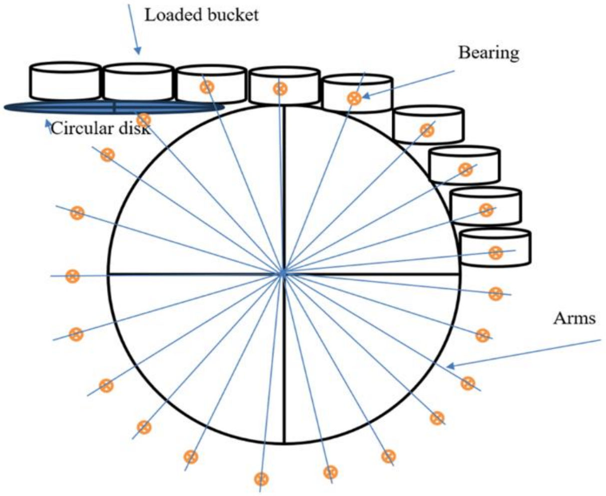
Circular horizontal disk with buckets

Figure-9A



Open Ends Railing

Figure-9B



Rotating circular escalator clipping buckets from sides with bearing

Figure-10

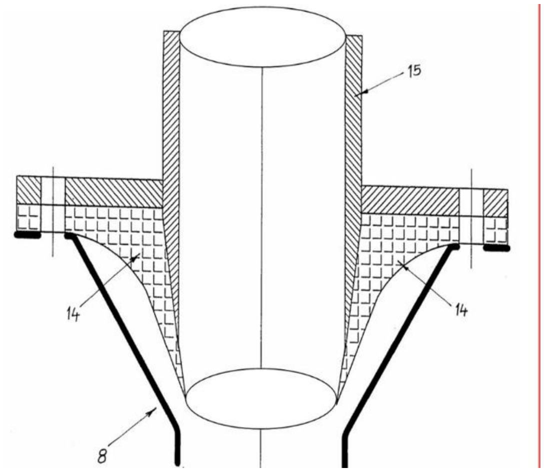


Figure-11

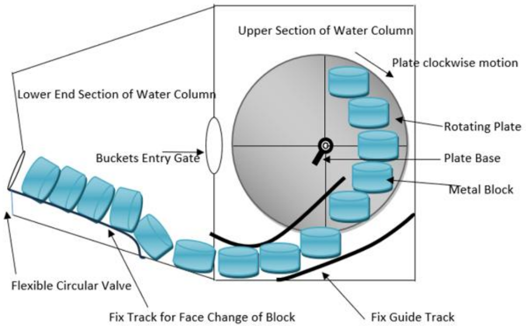


Figure-12A

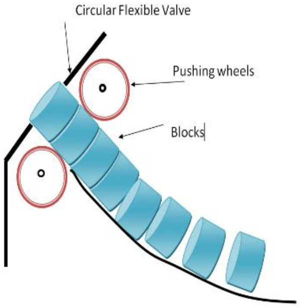


Figure-12B