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MODELING OF AN ARCHIMEDES SCREW HYDROELECTRIC MICRO-POWER PLANT TO SUPPLY A ROCK CRUSHING AND SCREENING FACTORY IN KINSHASA

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ABSTRACT

The Democratic Republic of Congo possesses considerable hydroelectric potential, estimated at approximately 100,000 MW, of which only 2 to 3% is currently exploited. Faced with the chronic energy deficit that particularly affects industrial zones, the LUTENDELE crushing and screening plant, located in Kinshasa, faces major difficulties in electricity supply, with daily load shedding reaching 8 hours and costly use of generator sets. This study aims to model an Archimedes screw hydroelectric micro-power plant to supply this plant. The adopted methodology combines analytical, quantitative and experimental approaches, including an electrical audit of the machinery, a hydrological characterization of the site, and a complete sizing of the structures. The electrical audit revealed a total installed power of 571 kW and a minimum required power of 244 kW to ensure production continuity. The hydrological analysis of the Congo River in the Pool Malebo area showed a low flow rate of 1.2 m^3/s, an average annual flow rate of 8.2 m^3/s, and a net head of 4.8 m. The sizing resulted in an Archimedes screw with an external diameter of 2.50 m, an internal diameter of 1.35 m, a pitch of 3.74 m, a threaded length of 8 m, an inclination of 25°, and a rotational speed of 25 rpm. The net electrical power delivered is 270 kW with an overall efficiency of 87.4%. The economic analysis indicates an annual saving of 481,000 USD and a payback period of 1.63 years. Environmentally, the project allows a reduction of 748 tons of CO_2 per year and preserves aquatic fauna thanks to the fish-friendly nature of the Archimedes screw.

Keywords: Micro-Hydroelectric Power Plant; Archimedes Screw; Renewable Energy; Sizing; Crushing Plant; Kinshasa

1 INTRODUCTION

The Democratic Republic of Congo (DRC) possesses one of the largest hydroelectric potentials in Africa, estimated at approximately 100,000 MW, of which only 2 to 3% is currently exploited. Paradoxically, the country experiences a chronic energy deficit, particularly marked in urban and industrial areas. Kinshasa, a capital city with over 15 millions inhabitants, is no exception to this rule: recurrent power outages and voltage fluctuations hamper economic development and the competitiveness of local companies.

In this context, the African crushing and screening plant of Lutendele, specializing in rock crushing and treatment for aggregate production destined for the construction sector, faces major electricity supply difficulties. The national electricity company (SNEL) fails to provide stable and sufficient power to operate crushers, vibrating screens, and belt conveyors continuously. As a consequence, the plant must often rely on heavy fuel oil-powered generator sets, generating high operating costs and polluting emissions incompatible with sustainable development goals.

The LUTENDELE crushing and screening plant currently consumes an estimated average electrical power of 295 kW. This demand is partially covered by the SNEL grid, but with daily load shedding reaching up to 8 hours. The complement is provided by two generator sets of 250 kVA each, whose operation costs about 800 USD per day in fuel alone.

The reversed Archimedes screw (screw turbine) has the advantage of operating under very low heads (from 1 to 5 meters) and variable flow rates. The general objective of this work is therefore to design a dimensional model of an Archimedes screw hydroelectric micro-power plant adapted to the factory site.

2 MATERIALS AND METHODS

2.1 Study Scope and Limitations

The study focuses exclusively on the site of the African crushing and screening factory in LUTENDELE, located in the Mont Ngafula commune in Kinshasa. Flow rate measurements were carried out over a maximum period of six months (three months of the dry season and three months of the rainy season). Thematically, only the inclined-axis Archimedes screw is modeled, and the gross head is limited to a maximum of 8 meters.

2.2 Methodological Approach

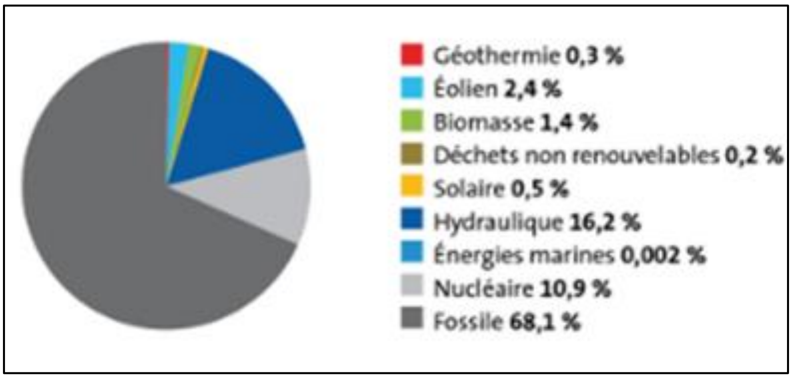
The adopted methodology combines three major approaches:

- Analytical Method: Used to study in-depth the physical phenomena involved in the operation of an Archimedes screw by establishing mathematical relationships between the parameters.
- Quantitative Method: Consists of collecting and analyzing numerical data (flow rates, power outputs, costs) to assess economic viability.
- Experimental Method: Relies on *in situ* data collection. The tools deployed include a low-flow gauging rod for river flow measurement and a clamp meter for electrical current measurements of operating machinery.

3 RESULTS AND DISCUSSION

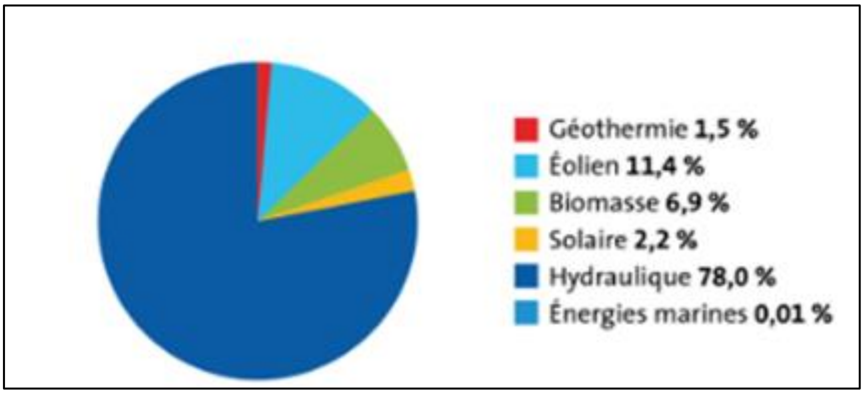
3.1 Global Energy Context and Hydroelectric Shares

Electricity production from global renewable energy sources increased in 10 years from 18.3% to 20.8%. Hydroelectric energy ranks first among all renewable energy sources.



(Source: Observ'ER) [3]

Figure 1: Structure of global electricity production



(Source: Observ'ER) [3]

Figure 2: Structure of global renewable energy production

Small Hydroelectric Power Plants (SHP) make it possible to exploit the hydraulic energy of smaller watercourses. They are categorized by power capacity according to UNIPEDE and by hydraulic head according to ADEME:

Table 1: Classification of Small Hydroelectric Power Plants

Name	Minimum Power (kW)	Maximum Power (kW)
Small plant	2000	10,000
Mini-plant	500	2000
Micro-plant	20	500
Pico-plant	—	20

(Source: UNIPEDE) [1]

Table 2: Different Types of Small Hydroelectric Power Plants

Type	Minimum Head (m)	Maximum Head (m)
High head	100	—
Medium head	15	100
Low head	—	15

(Source: ADEME) [1]

3.2 Comparative Analysis of Turbine Technologies

The choice of the turbine is primarily dictated by the net head and the design flow rate to be turbined. The Archimedes screw represents a highly competitive option for low heads.

Table 3: Comparison of Application Ranges for Different Turbines

Turbine Type	Head Range (m)	Flow Range (m^3/s)	Efficiency (%)
Archimedes Screw	0.1 – 10	0.01 – 10	70 – 94
Pelton	> 50	< 10	85 – 92
Francis	10 – 300	0.5 – 20	85 – 95
Kaplan	2 – 40	10 – 350	85 – 93
Waterwheel	< 6	< 1	60 – 80

(Source: YoosefDoost & Lubitz) [4]

3.3 Mathematical Modeling and Fish-Friendliness Criteria

Assuming that the turbine does not recover any kinetic energy from the fluid, the nominal hydraulic power developed by the screw is given by the classic equation:

$$P_{hyd} = \rho \cdot g \cdot Q \cdot H \qquad \text{(Eq. 1)}$$

Where ρ is the fluid density, g is the gravitational acceleration, Q is the flow rate, and H is the geodetic head. The overall micro-power plant efficiency (η_{MCH}) is expressed as follows:

$$\eta_{MCH} = \eta_{vis} \cdot \eta_{M} \cdot \eta_{G} \cdot \eta_{O} \qquad \text{(Eq. 2)}$$

One of the major environmental advantages of the Archimedes screw is its fish-friendly behavior, protecting aquatic fauna from injury during downstream migration.

Table 4: Fish-Friendliness Criteria for a Hydraulic Turbine

Cause	Consequences	Recommendation
Mechanical	Abrasion, grinding and impacts	Blade velocity < 6.1 m/s
Pressure gradient	Too slow fish adaptation rate	Pressure > 69 kPa, Pressure gradient < 550 kPa/s
Turbulence	Fish disorientation	Turbulence threshold at 180 m/s/m

(Source: Kiebel et al.) [5]

3.4 Synthesis of the Lutendele Micro-Power Plant Sizing

Applying the model to the specific context of the Lutendele site (net head of 4.8 m, exploitable flow rate of 8.2 m^3/s) resulted in the following optimal technical specifications:

- External screw diameter (R_a): 2.50 m
- Internal screw diameter (R_i): 1.35 m
- Screw pitch (S): 3.74 m
- Threaded length (L_B): 8 m
- Screw inclination (β): 25°
- Rotational speed (n): 25 rpm

This sizing ensures the delivery of a net electrical power of 270 kW with an overall efficiency of 87.4%, successfully covering the minimum 244 kW required power to maintain production continuity at the factory. Economic indicators show an excellent payback period estimated at 1.63 years.

4 CONCLUSION

This study successfully modeled an Archimedes screw hydroelectric micro-power plant for the Lutendele factory. This decentralized system offers a realistic and sustainable answer to the DRC's industrial energy deficit. Beyond eliminating heavy operational expenditures related to diesel generators, the project saves 748 tons of CO_2 emissions per year while fully conserving the local river ecology.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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The economic summary indicates only a depreciable investment cost, offset by an annual savings of USD 481,000, with a payback period of 1.63 years.

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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