Published by
NIGERIAN SOCIETY OF PHYSICAL SCIENCES
Available online @ https://journal.nsps.org.ng/index.php/jnsps

J. Nig. Soc. Phys. Sci. 5 (2023) 1263

Journal of the Nigerian Society of Physical Sciences

Generation of Electricity From a Hydraulic Turbine in the Djonou River (Benin)

Mahouton Justine Carine Adjassa[a], Gabin Koto N'Gobi[a,*], Hagninou Elagnon Venance Donnou[a], Clément Adéyèmi Kouchadé[a], Basile Bruno Kounouhewa[a]

[a]*Laboratoire de Physique du Rayonnement (LPR), University of Abomey-Calavi, Abomey-Calavi, 01 BP 526 Cotonou, Bénin*

Abstract

The shortage of electricity in rural areas despite the hydraulic potential they possess is becoming a challenge for Benin. To date, nearly 140,000 people spread over the 42 lakeside villages of this country live in energy inaccessibility, insecurity and poverty. To overcome this situation, the present study is therefore interested in the production of electrical energy on an experimental basis in low water periods thanks to an Archimedean screw turbine which operates at low flow rates and height of fall on the river. Djonou located in southern Benin a few kilometers from the University of Abomey-Calavi. The geometrical and hydraulic parameters of the screw were therefore determined and the device was modeled using Autocard software. A prototype was then made with local recycled materials and tested on the river. The screw specifications indicate an inside and outside radius of 0.072 m and 0.135 m. The length of the screw was set at 0.46 m for a blade radius estimated at 0.137 m. The number of screw blades is equal to 2 with a flow rate of 0.049 m^3/s. The inclination angle of the screw is 25°. The device on the experimental site produces a voltage of 16 V and provides a current of about 0.12 A which can power a 2 W lamp. This performance of the prototype made on a small scale is a reliable indicator of the optimal use of this technology in the national hydraulic network of Benin to supply populations with electrical energy.

DOI:10.46481/jnsps.2023.1263

Keywords: Hydroelectricity, Flow, experimentation, energy inaccessibility, Archimedean screw, low water period

Article History :
Received: 30 November 2022
Received in revised form: 12 March 2023
Accepted for publication: 14 March 2023
Published: 21 May 2023

Communicated by: B. J. Falaye

1. Introduction

Technological advances associated with population growth mean that the need for energy continues to increase. This problem is even more sensitive in rural areas where the use of conventional resources often proves to be very costly. In addition, there are several constraints, such as the geographical location of these areas and the very high cost of connecting electricity production sites to the conventional network, thus making the search for an alternative energy source essential. Recent studies and forecasts by the International Energy Agency (IEA) alert us and inform us that the massive use of fossil energy resources will certainly lead to the total depletion of these reserves.

The awareness of international opinion of the need to turn to green energies is therefore becoming more and more palpable in terms of the fight against global warming and the protection of the environment. The IEA explains that renewable energy resources are like those derived from natural processes and replenished at a rate faster than they are consumed [1]. They can therefore meet the growing energy demand and are ready to

*Corresponding author tel. no: +22997228700
Email address: kotgabin36@yahoo.fr (Gabin Koto N'Gobi)

provide the world with a reliable energy system [2, 3]. Among these sources, hydroelectricity is the leading source of renewable electrical energy with an installed global capacity of approximately 4306 terawatt hours per year, i.e. 70% of global renewable energy production and 15.6% of global electricity production in 2019 [4].

Unfortunately, the high cost of hydroelectric installations makes it difficult to access in underdeveloped countries, despite the fact that the latter are full of hydraulic resources. This is the case of Benin which has an important hydraulic potential unexploited until now. It is therefore necessary to think of means of energy production by hydroelectricity at a lower cost [5, 6, 7]. The Archimedean screw which is a technology that makes it possible to exploit low water flow rates and low head heights on hydroelectric sites such as small rivers or streams [8-16] and in areas remote areas that are difficult to access via the national electricity grid [17] is therefore an asset for Benin. Its design is environmentally friendly and allows fish and other aquatic life to pass through without danger; there is no requirement for deforestation, displacement of people and does not require construction of large dams, penstocks etc. [6, 13, 14, 18, 19].

In order to improve the performance of this technology, several investigations have been carried out in the literature. In the work of Yulistiyanto *et al.* [20], Maulana *et al.* [13], Alkistis *et al.* [19], Maulana *et al.* [15], Abdul *et al.* [9], Khan *et al.* [21], Betancour *et al.* [22], Abdillah *et al.* [23], Imawati *et al.* [24], Eswanto *et al.* [25], Erinofiardi *et al.* [26] the authors studied the influence of the geometric and hydraulic parameters of the Archimedes screw, namely the angle of inclination of the shaft, the number of blades, the variations in flow, the slope of the shaft , the direction of the axis of rotation, the speed of rotation, its angle of slope, the diameter ratio between the inner and outer diameters, the length of the axis and the pitch on the power and efficiency of the screw. According to the work of Warjito *et al.* [6], the authors believe that the Archimedes turbine has no fixed design theory.

Several theories and design-simulation procedures have therefore been developed for this turbine by certain authors such as Alonso-Martinez *et al.* [10], Saroinsong *et al.* [11], Purece, and Corlan [12], Dellinger *et al.* [14], Slaboch *et al.* [18], Fiardi [27], Siswantara *et al.* [28], Yulianto *et al.* [29], Dragomirescu [30], Thombare *et al.* [31], Rosly *et al.* [32], Abdullah *et al.* [33], Muller [34], Yulianto *et al.* [35], Rohmer *et al.* [36], Simmons *et al.* [37], Erinofiardi *et al.* [38], Yoosef-Doost and Lubitz [39], Hedia *et al.* [40] followed by an on-site or laboratory experimentation phase discussed by some authors. Ubando *et al.* [41] for their part have examined different methods of manufacturing Archimedean screw turbines such as the 3D printing method still in their early stages of development and additive manufacturing as having a relatively lower environmental impact than conventional manufacturing of turbine blades. Gogoi *et al.* [5] and Kumar *et al.* [6] meanwhile have shown that the electrification scenario in rural areas can be improved specially where there is a continuous flow of a river or a canal with small water flow by the installation of the low-cost Archimedes screw turbine. Darmono and Pranoto [42] investigated the numerical analysis of the effect of the number of threads on the turbine blades by the computational fluid dynamics method and ANSYS FLUENT software. Velásquez *et al.* [43] used a gravitational vortex hydraulic turbine (GWVHT) to determine the optimal position (h) of the slide to increase the efficiency of the hydroelectric plant using computational fluid dynamics (CFD). This hydroelectric technology is low head and has a vertical channel to extract energy from water vortices.

Based on these findings and to demonstrate the feasibility of using this technology in Benin, this study aims to carry out and experiment with the Archimedes screw on a small scale on a river in southern Benin near the University of Abomey-Calavi. In a specific way in a first time, the geometrical and hydraulic parameters are determined. Then a design of the system under Autocard followed by a realization of the device with local materials of recovery are made. Finally, on-site experimentation will make it possible to ensure the operation of the turbine and to identify a few electrical quantities. This test, which constitutes a first experience of an Archimedean screw turbine in Benin, will be carried out during low water periods when the water levels are low in order to better assess the efficiency of the device.

2. Materials and Methods

2.1. Materials

2.1.1. Study site

The Djonou River is located in the south of Benin in the commune of Abomey-Calavi, Arrondissement of Godomey and about 1 km from the University of Abomey-Calavi. It crosses the Houédonou bridge to reach Lake Nokoué, which is the largest lake in Benin. It can be located at longitude $2°18'44.291"E$ and latitude $6°24'529"N$. This area is characterized by two rainy seasons (April-July; October-November) and two dry seasons (December-March; August-September). The average interannual rainfall in the study area is 1100 mm [44]. This site was chosen to test the prototype that will be produced with the aim of producing electricity to supply a domestic load. Figure 1 provides an overview of the study region and its location in Africa.

2.1.2. Data used

Various measurements were carried out on the study site during the low water period in order to determine the minimum hydraulic parameters of this river. The data collected are, among other things, the speed of the water flow and the depth of the river. The depth varies according to the bathymetry. To assess the flow in the absence of a measuring device, we had defined distances on the water several times and placed a light polystyrene object on it which will have to cover these predefined distances. The movement of the object between two positions was timed. Note that this measurement was carried out several times in order to reduce measurement errors. From these two parameters, we estimated the average speed of water flow. From the section of the Archimedes screw the flow rate of the water will be determined. Table 1 gives some experimental values of the hydraulic parameters of the Djonou River during the low water period.

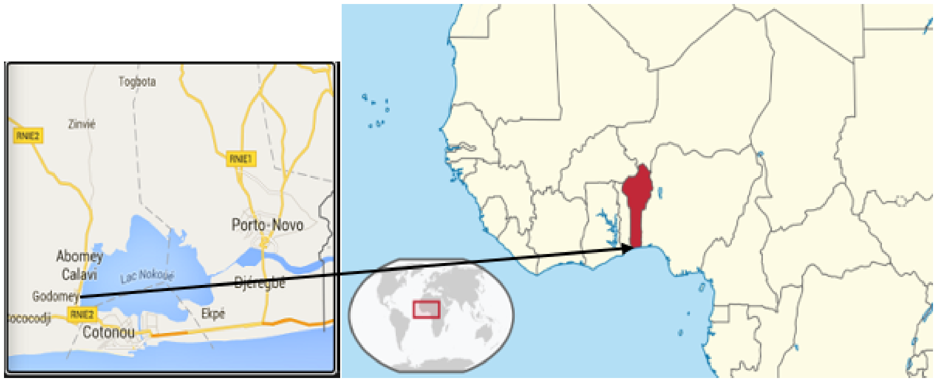

Figure 1: Geographical location of the Djonou River in Godomey in Benin. Location in Africa

Table 1: Some experimental values of hydraulic parameters

Land length close (m)	Speed of flow (m/s)	Depth of the lake (m)
0.5	0.62	0.80
1	0.65	1.25
1.5	0.71	2.5
2	0.79	3.5
2.5	0.83	4
3	0.96	4.8
4	1.25	5

2.2. Methods

2.2.1. Geometric and hydraulic parameters

To determine the geometrical and hydraulic parameters of the Archimedes screw, certain characteristics will be fixed to facilitate the study. In Figure 2, the screw parameters are shown.

The geometric parameters of an Archimedean screw are:

- the outer radius R_a
- the inner radius R_i
- the pitch of the screw S
- the total length L
- the threaded length L_b
- the number of blades N
- the inclination of the screw β

The hydraulic parameters are:

- the inflow Q
- the geodesic head H

In the work of [45], the author asserts that the screw performs well when the angle of inclination varies from 22° to 45° We therefore fixed the value of this angle at $\beta = 25°$. The number of blades used for the design of the turbine is fixed at N equal to 2 referring to the work of Maulana *et al*. [14] who showed that turbines with two blades have a more inclined pressure distribution so that it has better stability. The length of the screw L_b is taken equal to 0.46 m. The geodesic drop height is set at 0.3 m depending on the topography of the site. Finally, the outer radius R_a is 0,135m.

In order to determine the various geometric parameters of the screw, the determination of the radius ratio (ρ), the inclination ratio (λ), the volume ratio (v) and the volume ratio per revolution ($\lambda.v$) is paramount [8, 16, 17, 28, 45]:

$$\rho = \frac{R_i}{R_a}. \quad (1)$$

$$\lambda = \frac{S_v \tan(\beta)}{2\Pi R_a}. \quad (2)$$

$$V = \frac{V_u \tan(\beta)}{\Pi R_{a^2} S_v}, \quad (3)$$

where R_i is the inner radius in m; S_v denotes the surface in mm^2. V_u, the volume of the displaced fluid per revolution (m^3), is a function of ($\lambda.V$) [12, 46] and given by :

$$V_u = \frac{2\Pi^2 R_a^3 (\lambda.V)}{\tan\beta}. \quad (4)$$

The radius ratio ρ must of course be between 0 and 1 [46]. Table 2 is a summary of the different values of these parameters depending on the number of blades.

From Eq.(1), we can deduce the inner radius R_i(m) :

$$R_i = \rho R_a. \quad (5)$$

The pitch S (m) which constitutes the distance between the blades is determined using the inclination ratio λ contained in table 2 [16, 36, 46]:

$$S = \frac{2piR_a\lambda}{\tan(\beta)}. \quad (6)$$

The determination of the distance between the trough and the screw S_{sp} (m) is given by Eq. (7) [36, 46]:

$$S_{sp} = 0.0045\sqrt{2R_a}. \quad (7)$$

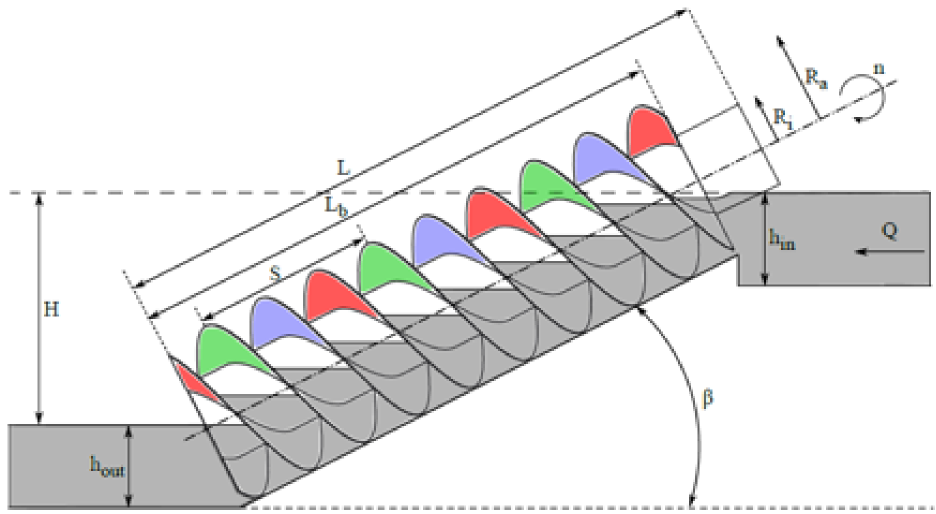

Figure 2: Representation of the hydraulic and geometric parameters of an Archimedean screw micropower [45]

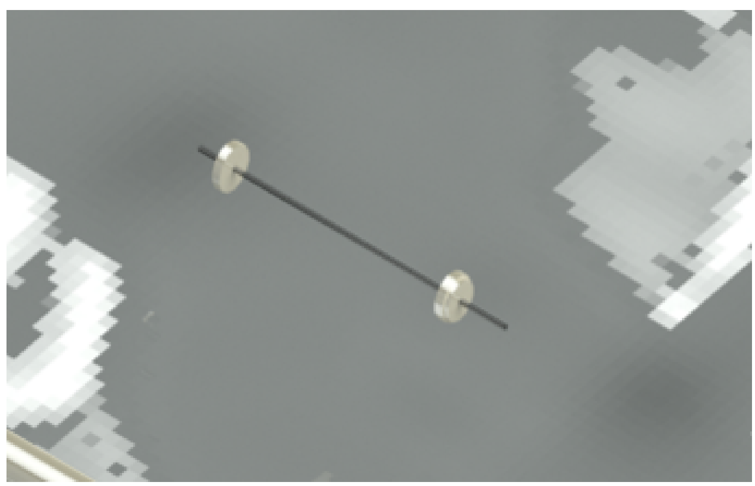

Figure 3: Modeling of the Archimedean screw rod

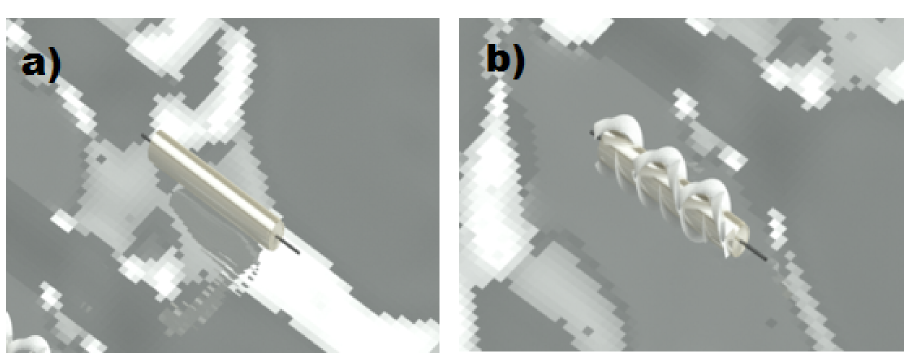

Figure 4: Modeling of the (a) central shaft of Archimedean screw and (b) the threads around the shaft Archimedean screw

The dimensions of the trough R (m) are a function of the outside radius of the auger and the distance between the trough and the auger:

$$R = S_{sp} + R_a. \tag{8}$$

The hydraulic parameters of the Archimedean screw are deter-

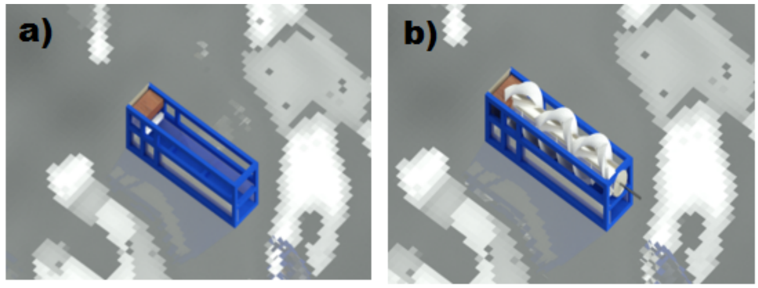

Figure 5: (a) Built-in support of the Archimedean screw trough and (b) Modeling of the Archimedean screw contained in the trough

Figure 6: Archimedean screen: (a) Prototype of the Archimedean screw made and (b) measurement of the tension during the experiment on the site

Table 2: Archimedean screw ratio parameters for different numbers of blades [47]

Number of blades (N)	Radius ratio (ρ)	the inclination ratio (λ)	Volume (m) ratio (V)	Volume ratio per revolution ($\lambda.V$)
1	0.5358	0.1285	0.2811	0.0361
2	0.5369	0.1863	0.2747	0.0512
3	0.5357	0.2217	0.2697	0.0588
4	0.5353	0.2456	0.2667	0.0655
5	0.5352	0.2630	0.2647	0.0696

mined by Eqs. (9-15). The volume flow $Q(m^3/s)$ is calculated by:

$$Q = S_v V. \tag{9}$$

With S_v the area of the right session in (m^2) and V the average speed of the fluid flow (m/s). The flow rate Q of water flowing through an Archimedean screw can be broken down as follows [28, 36]:

$$Q = Q_e + Q_f + Q_s, \tag{10}$$

where Q_e is the effective Q_f water flow, the leakage rate between the trough and the blades and Q_s the leakage rate due to overfilling. When the screw is under filled or at the optimal filling point, the flow rate Q_s is zero. Several flow rates are involved in determining the operating flow rate of the screw Q_e. The most commonly used leakage flow model is that established for the Archimedes screw pump. The leakage rate Q_f is given by equation (11) [34, 46] :

$$Q_f = 5S_{sp}R_a\sqrt{2R_a}. \tag{11}$$

The axial transport speed is given by equation (12) [12, 48]:

$$C_{ax} = \frac{Sn}{60}, \tag{12}$$

where $n(rpm)$ is the rotational speed of the Archimedean screw which is given by [28, 46]:

$$n = \frac{56}{(2R_a)^{\frac{2}{3}}}, \tag{13}$$

with C_{ax} as the axial speed in m.tr/s, and P is the pitch of the screw. The average wetted surface S_{moy} (m^2) orthogonal to the axis of the screw is defined in order to express the flow rate Q_e as a function of C_{ax}:

$$S_{moy} = \frac{V_u}{SN}. \tag{14}$$

N is the number of blades or threads of the turbine. The flow rate Q_e is then given by [12, 48]:

$$Q_e = \frac{nV_uN}{60}. \tag{15}$$

2.2.2. Mechanical and electrical power

The mechanical power of the screw shaft P_m is determined from Eq. (16) [12, 16, 33]:

$$P_m = \eta_t \rho_{water} g Q H, \quad (16)$$

where η_t is the efficiency of the screw. In the case of this study, the efficiency of the screw is taken as 92% [32]. H is the geodesic drop height. The torque of the Archimedes screw M (N.m) is given by Eq. (17):

$$M = \frac{60 P_m}{2\Pi n}. \quad (17)$$

The electrical power P_e of an Archimedean screw turbine is determined as follows:

$$P_e = \eta_g P_m. \quad (18)$$

where η_g is the generator efficiency (95%).

3. Results and discussion

3.1. Results

3.1.1. The characteristics of the Archimedean screw

In Table 3, the dimensions of the Archimedean screw are summarized.

Table 3: Archimedean screw dimension

Settings	Description	Dimension
R_i	Inner radius (m)	0.072
R_a	Outer radius (m)	0.135
S	Pitch (m)	0.0107
β	Angle of inclination of the screw	25
S_{sp}	distance between the auger and the trough (m)	0.0023
S_v	surface of the trough (m^2)	0.0592
R	radius of the trough (m)	0.137
n	rotational speed (rpm)	134
N	number of blades	2
C_{ax}	axial speed (m.tr/s)	0.023
V_u	per revolution (m^3)	0.0053
V	water velocity (m/s)	0.83
L_b	screw length	0.46
S_{moy}	average wet surface (m^2)	0.46
Q_f	the leak rate (m^3/s)	0.000806
Q_e	effective water flow (m^3/s)	0.0236
Q_s	the overfill flow (m^3/s)	0.024
Q	river flow (m^3/s)	0.049
H	drop height (m)	0.30
P_m	mechanical power (W)	133
M	the torque at the screw (N.m)	9.48
P_e	theorical electrical power (W)	126

The values observed in this study were compared with those obtained by other authors in the literature who have designed and experimented with the Archimedean screw (Table 4).

The geometric and hydraulic characteristics of Archimedean screws collected in the works of Brada, 1993, 1999 [49, 50], Lashofer *et al.* [51, 52, 53], Lubitz *et al.* [54], Lyons [55], Yulistiyanto *et al.* [20], Maulana *et al.* [12], Saroinsong *et al.* [8], Alonso-Martinez *et al.* [7], Khan, *et al.* [17], Rohmer *et al.* [36], Erinofiardia *et al.* [38] and Dellinger *et al.* [48] indicate that the interior and exterior radius of the Archimedean screw vary respectively from 0.030 m to 0.525 m and from 0.055 m to 0.265 m. The pitch of the screw is between 0.054 m and 1.22 m with a number of screw blades ranging from 1 to 10. The angle of inclination of the screw is generally chosen between 17° and 45° The length of the screw and the water flow rate can reach 5.3 m and 1.2 m^3/s respectively. Drop heights varying from 0 to 2.5 m are encountered with rotation speeds of up to 395 rpm. Except for the pitch of the screw, these parameters are similar and close to those obtained in this study. These values therefore confirm the results of the present study.

3.1.2. Modeling of the Archimedean screw under Autocard

The Archimedean screw is the main element of this design because it is the basis for the production of electrical energy. But it is really essential to know that it is she who produces the mechanical energy thanks to the potential energy of the water which causes the latter in its rotation. Figure 3 gives an overview of the design of the Archimedean screw rod in Autocard.

Figures 4 and 5 show the modeling of the Archimedean screw shaft, the threads around the screw shaft, the incorporated support of the trough and the contained Archimedean screw respectively. in the trough.

3.1.3. Practical realization

The description of the essential elements having participated in the realization of the device is as follows:

- Nets: We used number 45 polyvinyl chloride (PVC) to make the threads (blade) of the screw, taking into account the geometric parameters mentioned. Similarly, we used polyvinyl chloride (PVC) number 16 with its covers to make the central axis of the screw on which we place the threads of the screw. PVC was used not only because it is light and easy to move with a small amount of water on its surface, but also because its maintenance will be very simple compared to other materials such as aluminum;

- Drive shaft: We used a metal rod for the screw drive shaft. It connects the screw to the generator via other elements in order to transmit the rotation speed to the generator;

- Bolts: They allowed us to fix certain elements of the turbine to their different locations without friction. The elements fixed by the bolts are among others: the shaft of the turbine, the bicycle chainring and the driving tooth;

- Speed multiplier: we used a number 12 bicycle cog that we attached to the shaft of the screw to drive the generator with a chain and another motor cog with a radius smaller

Table 4: Comparacian de las especificaciones para cada diseao del sistema.

Authors	Inner radius (m)	Outer radius (m)	Screw pitch (m)	Threaded length (m)	Number of blades	Screw inclination (°)	Debit (m^3/s)	Drop height (m)	Rotation speed (rpm)
Brada [49, 50]	0.525	0.265	1.05	5.3	3	26-34	0-0.35	1.8-2.2	48-79
Lashofer *et al.* [51, 52, 53]	0.403	0.18-0.22	0.8-1.2	3	3-5	18-32	0.02-0.22	0.5-1.7	20-80
Lubitz *et al.* [54]; Lyons [55]	0.038	0.078	0.117-0.2	0.584	3	17-35	0.0004-0.0012	0.14-0.28	0-280
Yulistiyanto *et al.* [20]	0.076	0.142	0.22	-	2	35	0.00364	-	-
Maulana *et al.* [16]	0.077	0.143	0.287	2	-	-	0.025	-	295
Saroinsong *et al.* [12]	0.030	0.055	0.132	0.055	3	30	-	-	395
Alonso-Martinez *et al.* [11]	0.032	0.56	0.972	3.20	3	22	1.2	< 2	73.2
Abdullah *et al.* [33]	0.07	0.13	0.07	1	1	30-45	-	-	-
Khan, *et al.* [21]	0.426	0.80	1.22	5.2	1-10	-	0.82	2.2	-
Rohmer *et al.* [36]	0.21	0.42	0.96	-	3	30	0.15	2.5	-
Erinofiardia *et al.* [38]	0.032	0.142	0.054	0.646	1	22	0.0012	0.25;0.38;0.41	106
Dellinger *et al.* [48]	0.052	0.09	0.192	0.40	3	18-30	0.001-0.004	0-0.35	-
Present study	0.072	0.135	0.0107	0.46	2	25	0.049	0.30	134

than that of the bicycle. Thanks to this association, the transmission ratio will be 8, which means that when the Archimedes screw turns once, the generator turns eight times in order to have a high rotation speed, hence the speed multiplier effect;

- Driving chain: We used the power chain not only because these links are better suited to our system but also because it is available;
- Generator: It receives the mechanical work provided by the screw to produce electrical energy continuously. We used a generator with 40 W power, 310 V DC voltages, 1500 rpm rotation speed and 0.129 A current;
- Trough: the trough is the most important element for the safety of auger users. It is the one that will inhabit the Archimedes screw and will also reduce the sound noise produced by the Archimedes screw. We incorporated the trough as well as the deflector in an aluminum support in order to facilitate the movement of the turbine.

Figure 6 shows a display of the multimeter (voltage) when the screw is moving following the flow of water on the Djonou river. During the experimental phase, the device was able to power a 2 W electric lamp under a voltage of 16 V by supplying a current of approximately 0.12 A. The power produced is estimated at 1.92 W for a flow rate of 0.049 m^3/s.

3.2. Discussion

By comparing the electrical quantities obtained in this study with the experiments carried out in the literature on similar and small-scale devices, we note in the work of Yulistiyanto *et al.* [20], Fiardi *et al.* [27], Maulana *et al.* [16], Saroinsong *et al.* [12], Abdullah *et al.* [33] that the authors obtained output powers estimated respectively at 16.23 W (61.61%); 0.098W; 116.10 W (0.025 m^3/s; 55%); 16.97W (350 rpm); 9.03 W (2.06 10^{-3} m^3/s; 72%). Similarly, the experimental performances of the screw turbine for very low head hydroelectric resources are presented in the work of Erinofiardia *et al.* [38]. The screw turbine with an outer diameter of 142 mm and a water flow of 0.0012 m^3/s with a head of 0.25 m, can produce a maximum power of 1.4 W with an efficiency 49% at 22° bank angle. These different powers recorded on small-scale Archimedean screw turbines are corroborated by the results obtained in this study. However, some power values are higher than the values presented for this study. The optimal determination of the height of fall, the length of the screw using the angle of inclination and the investigation of the relationship of the input speed to the angular speed of a wheel on the yield, could therefore avoid the overflow leaks noted on our device (leakage rate at overfilling evaluated at 0.024 m^3/s) due to loading and thus improve the performance of the turbine produced.

4. Conclusion

In this study, an Archimedean screw hydraulic turbine was designed, built and tested on the Djonou River in Benin. The characteristics of the device made from local recycled materials made it possible to measure a few electrical quantities, in particular the voltage and the intensity of the current. The main results of this work can be summarized as follows:

- The geometrical parameters of the Archimedes screw turbine indicate an internal and external radius evaluated respectively at 0.072 m and 0.135 m. The number of screw blades is equal to 2 with the radius of the trough estimated at 0.137 m. The threaded length is 0.46 m for an inclination angle of 25°;
- The hydraulic parameters give a flow rate of 0.049 m^3/s for a fall height of 0.3 m;
- The theoretical maximum electrical power of the device is 126 W. During the experimental phase on site, the device produced a voltage of 16 V and provides a current

intensity evaluated at 0.12 A which made it possible to power a lamp of 2W for a flow of 0.049 m^3/s. The experimental power is estimated at 1.92 W.

This experimentation, which constitutes a pilot phase which will result in large-scale production, requires improvements in order to increase the performance of the Archimedes screw, particularly in terms of its geometric parameters. In the future, we are therefore thinking of modifying the geometry of the screw in order to study its impact on electricity production.

Acknowledgments

The authors of this article sincerely thank the Bachelor school in renewable energies of the Faculty of Science and Technology (FAST) of the University of Abomey-Calavi (UAC) through the "Laboratoire de Physique du Rayonnement (LPR)" and the MasterCard of Abomey-Calavi University for funding our participation to the 3rd German-West African Conference on Sustainable and Renewable Energy Systems SusRES at the University of Kara in Togo.

References

[1] S. I. Akinsola, A. B. Alabi, M. A. Soliu, & T. Akomolafe, "Optimization of Method and Components of Enzymatic Fuel Cells", Nig. Soc. Phys. Sci. **1** (2019) 143.

[2] A. A. Willoughbya, A. O. Sogea, O. F. Dairoa, O. D. Olukannib, E. U. Durugboc , W. S. Michaela & T. A. Adebayod, "Fabrication and Characterization of a Dye-Sensitized Solar Cell using Natural Dye Extract of Rosella (Hibiscus sabdariffa L.) as Photosensitizer", J. Nig. Soc. Phys. Sci. **3** (2021) 287.

[3] M. S. Su'ait, M. Y. A. Rahman & A. Ahmad, "Review on polymer electrolyte in dye-sensitized solar cells (DSSCs)",Solar Energy **115** (2015) 452.

[4] S. Naranjo-Silva, D. Punina-Guerrero, J. Barros-Enriquez, J. Almeida-Dominguez, J. Alvarez del Castillo, "Hydropower Development in Three South American Countries: Brazil, Colombia, and Ecuador", Journal of Energy and Environment **14** (2023) 102.

[5] P. Gogoi, M. Handique, S. Purkayastha & K. Newar, "Potential of Archimedes Screw Turbine in Rural India Electrification: A Review", ADBU Journal of Electrical and Electronics Engineering (AJEEE) **2** (2018) 30.

[6] U. Kumar, P. Singh & A.C. Tiwari, "Suitability of Archimedes Screws for Micro Hydro Power Generation in India", International Journal of Thermal Technologies **6** (2016) 273.

[7] P. Punys & L. Jurevicius, "Assessment of Hydropower Potential in Wastewater Systems and Application in a Lowland Country Lithuania", Energies **15** (2022) 5173.

[8] Budiarso, Warjito, Dendy Adanta dan M.H. Gumelar Syafei, "Development of Archimedes Turbine Research: Review Article". Budiarso dkk / Prosiding SNTTM XVI, (2017) 177.

[9] O. S. Abdullah, W. H. Khalil, A H. Kamel & A. J. Shareef, "Investigation of Physical and Numerical Model of Archimedes Screw Turbine", Journal of Power and Energy Engineering, **8** (2020) 26.

[10] A. C. A. Salam, J. M Issac & B. Markose, "Numerical study of archimedean screw turbine", International Research Journal of Engineering and Technology (IRJET) **5** (2018) 2401.

[11] Alonso-Martinez, J. L. S. Sierra, J. Jo. del Coz Dëaz and J. E. Martinez-Martinez, "A New Methodology to Design Sustainable Archimedean Screw Turbines as Green Energy Generators". Int. J. Environ. Res. Public Health **17** (2020) 9236.

[12] T. Saroinsong, R. Soenoko, S. Wahyudi & M. N. Sasongko. "Fluid Flow Phenomenon in a Three-Bladed Power-Generating Archimedes Screw Turbin", Journal of Engineering Science and Technology Review **9** (2016) 72.

[13] C. Purece & L. Corlan, "Archimedean screw as fish-friendly turbines for harnessing hydropower potentia", E3S Web of Conferences **286** (2021) 02007-1.

[14] M. I. Maulana, A. Syuhada & M. Nawawi, "Blade Number Impact On Pressure And Performance Of Archimedes Screw Turbine Using CFD". The 3rd International Conference on Industrial, Mechanical, Electrical, and Chemical Engineering AIP Conf. Proc. **1931** (2018) 030037-1.

[15] G. Dellinger, P-A. Garambois, M. Dufresne, A. Terfous, J. Vazquez & A. Ghenaim. "Numerical and experimental study of an Archimedean Screw Generator". IOP Conf. Series: Earth and Environmental Science **49** (2016) 102002-1.

[16] M. I. Maulana, A. Syuhada & R. Kurniawan, "Experimental Study on the Effect of Flow rate on the Performance of Two-Blade Archimedes Screw turbine", Journal of Advanced Research in Fluid Mechanics and Thermal Sciences **61** (2019) 10.

[17] D. P. Sari, M. A. Ade Saputra, I. Syofii & D. Adanta, "A Study of The Developing Archimedes Screw as A Turbine", Journal of Advanced Research in Fluid Mechanics and Thermal Sciences **87** (2021) 151.

[18] P. E. Slaboch & J. Coday, "Design and analysis of small-scale horizontal archimedean screw for electric power generation", Proceedings of the ASME International Mechanical Engineering Congress and Exposition IMECE Florida USA (2017) 1.

[19] A. V. Stergiopoulou, V. G. Stergiopoulos, D. I. Tsivolas & A. S. Stylianou. "Two innovative experimental archimedean screw energy models in the shadow of archimedes", 5th International Conference on Experiments/Process/System Modeling/Simulation/Optimization 5th IC-EpsMsO Athens (2013) 641.

[20] B. Yulistiyanto, Y. Hizhar & Lisdiyanti, "Effect of flow discharge and shaft slope of archimides (screw) turbine on the micro-hydro power plant", Dinamika TEKNIK SIPIL **12** (2012) 1.

[21] A. Khan, A. Khattak, A. Ulasyar, K. Imran & M. A. Munir, "Investigation of Archimedean Screw Turbine for Optimal Power Output by Varying Number of Blades". Proc. of the 1st International Conference on Electrical, Communication and Computer Engineering (ICECCE) Swat, Pakistan (2019) 978-1.

[22] J. Betancour, L. Velásquez, L.Y. Jaramillo, E. Chica & A . Rubio-Clemente, "Application of a central composite face-centered design in the optimization of an Archimedean hydrokinetic turbine", 19th International Conference on Renewable Energies and Power Quality. (ICREPQ'21). Almeria (Spain) **19** (2021) 418.

[23] H. F. Abdillah, O. Dinaryanto & B. Jalaali "Manufacturing process and experimental study of a small scale archimedes hydro powerplant by varying the number of blade", Angkasa Jurnal Ilmiah Bidang Teknologi **14** (2022) 65.

[24] I. Imawati, M. Febiansyah, E. K. Garuda Novtrianda & H. Mubarok "Portable Pico-hydro Power Plant with Archimedes Screw Turbine in Pelangi Reservoir of Universitas Islam Indonesia", Jurnal Teknik Elektro **14** (2022) 132.

[25] E. Eswanto, H. Hasanb & Z. M. Razlan "An Analysis on Performance of Pico-hydro with Archimedes Screw Model Viewed from Turbine Shaft Angle", International Journal of Engineering, Transactions A: Basics **36** (2023) 10.

[26] E. Erinofiardi, R. Koirala, N. Shiwakoti & A. Date "Sustainable Power Generation Using Archimedean Screw Turbine: Influence of Blade Number on Flow and Performance", Sustainability **14** (2022) 15948-1.

[27] E. Fiardi. "Preliminary Design of Archimedean Screw Turbine Prototype for Remote Area Power Supply", Journal of Ocean, Mechanical and Aerospace -Science and Engineering, **5** (2014) 30.

[28] A. I. Siswantara, M. H. G. Syafei, M. A. Budiyanto, H. Pujowidodo, C. D. Widiawaty & G. G. Ramdlan Gunadi, "Design procedure of archimedes hydro turbine. Journal of southwest jiaotong university", **56** (2021) 335.

[29] Yulianto, B. Priyadi, Fathoni & H. Sucipto. "Design and Testing of Screw Turbines for Flat Flow with Uneven Blade Distances". American Journal of Engineering and Applied Sciences **12** (2019) 10.

[30] A. Dragomirescu. "Design considerations for an Archimedean screw hydro turbine", IOP Conf. Series: Earth and Environmental Science **664** (2021) 012034-1.

[31] S. P. Thombare, V. D. Nichit & P. K. Hire, "Power Generation by Screw Type Turbine", International Journal of Advanced Research in Computer and Communication Engineering ISO 3297 **6** (2017) 230.

[32] C. Z. Rosly, U. K. Jamaludin, N. S. Azahari, M. A. N. Mu'tasim, A. N.

Oumer & N. T. Rao. "Parametric study on efficiency of archimedes screw turbine", ARPN Journal of Engineering and Applied Sciences **11** (2016) 10904.

[33] O. S. Abdullah, W. H. Khalil, A. H. Kamel & A. J. Shareef, "Investigation of Physical and Numerical Model of Archimedes Screw Turbine", Journal of Power and Energy Engineerin **8** (2020) 26.

[34] G. Möller. "Simplified theory of Archimedean screws", Journal of Hydraulic Research **47** (2009) 666.

[35] Yulianto, A. Komarudin, B. Priyadi, Subiyantoro & Fathoni, "Design of Turbine Screw Model for Pico-Hydro", American Journal of Engineering Research (AJER) **6** (2017) 130.

[36] J. Rohmer, D. Knittel, G. Sturtzer, D. Flieller & J. Renaud, "Modeling and experimental results of an Archimedes screw turbine", Renewable Energy **94** (2016) 136.

[37] S. Simmons, G. Dellinger, A. A. Aliabadi & W. D. Lubitz, "Dynamic overflow leakage in Archimedes screw generator", Proceedings of the Canadian Society for Mechanical Engineering International Congress 2021 CSME Congress Charlottetown PEI Canada (2021) 1.

[38] E. Erinofiardia, A. Nuramalb, P. Bismantolob, A. Datea, A. Akbarzadeha , A. K. Mainilb & A. F. Suryonob, "Experimental study of screw turbine performance based on different angle of inclination", Energy Procedia 1st International Conference on Energy and Power RMIT University, Melbourne, Australia **110** (2017) 8.

[39] A. YoosefDoost & W. D. Lubitz, "Archimedes Screw Design: An Analytical Model for Rapid Estimation of Archimedes Screw Geometry", Energies **14** (2021) 7812-1.

[40] A. I. Hedia, E. M. Mouris & O. Shehata, "Design and analysis of Analytical Model of an Archimedes Screw Turbine", International Journal of Advances in Scientific Research and Engineering **8** (2022) 58.

[41] A. T. Ubando, I. A V. Marfori, M. S. Peradilla, C. L. Sy, A. M. A. Calapatia & W.-H. Chen,"Sustainable Manufacturability of Archimedes Screw Turbines: A Critical Review", J. Manuf. Mater. Process. **6** (2022) 161-1.

[42] B. Darmono & H. Pranoto, "Archimedes Screw Turbines (ASTs) Performance Analysis using CFD Software Based on Variation of Blades Distance and Thread Number on The Pico Hydro Powerplant", International Journal of Advanced Technology in Mechanical, Mechatronics and Materials (IJATEC) **3** (2022) 18.

[43] G. L. Velásquez, A. Rubio-Clemente & E. Chica,"Runner optimal position in a gravitational water vortex hydraulic turbine with a spiral inlet channel and a conical basin", 20th International Conference on Renewable Energies and Power Quality (ICREPQ'22) **20** (2022) 143.

[44] F. Afouda, P. M. Adéogou, I. Salako & I. Yabi, "Instabilité intrasaisonnière des pluies de la grande saison agricole dans la commune de Kétou au Bénin", Revue de géographie du laboratoire Leédi **2** (2014) 26.

[45] G. Dellinger, "Etude expérimentale et optimisation des performances hydrauliques des vis d'Archimède utilisées dans les micros centrales hydroélectriques". Thèse Science politique. STRASBOURG : école Doctorale MSII (2015).

[46] S. A. Raza, "Genarating electricity by using sewage water". Thesis submitted to the graduate school of applied sciences: Near East University, Nicosia (2015).

[47] C. Rorres, "The Turn of the Screw: Optimal Design of an Archimedes Screw", Journal of Hydraulic Engineering **126** (2000) 72.

[48] G. Dellinger, A. Terfous, P.-A. Garambois & A. Ghenaim, "Experimental investigation and performance analysis of Archimedes screw generator", Journal of Hydraulic Research, Taylor & Francis **54** (2016) 197.

[49] K. Brada, "Einaches kleinkraftwerke mit schneckenturbine zur betrieblichen stromerzeugung", MM. Maschinenmarkt **99** (1993) 30.

[50] K. Brada, "Wasserkraftschnecke ermöglicht stromerzeugung über kleinkraftwerke", MM. Maschinenmarkt **105** (1999) 52.

[51] A. Lashofer, W. Hawle & B. Pelikan, "State of technology and design guidelines for the archimedes screw turbine" In Hydro (2012). Wallington, Surrey, U.K.

[52] A. Lashofer, W. Hawle, and B. Pelikan, "Betriebsbereiche und wirkungsgrade der wasserkraftschnecke. Wasserwirtschaft" **103** (2013) 29.

[53] A. Lashofer, F. Kaltenberger & B. Pelikan, "Does the archimedean screw turbine stand the test ? Wasserwirtschaft", **101** (2011) 310.

[54] W. D. Lubitz, M. Lyons & S. Simmons, "Performance model of archimedes screw hydro turbines with variable fill level". Journal of Hydraulic Engineering, **140** (2014) 04014050-1.

[55] M. W. K. Lyons, "Lab Testing and Modeling of Archimedes Screw Turbines". PhD thesis, The University of Guelph (2014).