INVESTIGATING THE HYDRODYNAMIC BEHAVIOR OF INNOVATIVE ARCHIMEDEAN HYDROPOWER TURBINES

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ABSTRACT
The present paper presents the preliminary investigation of the hydrodynamic behavior of Archimedean hydropower turbines, with inclined and horizontal axis, for the exploitation of the low-head hydraulic energy and the kinetic energy of natural and artificial watercourses, including coastal and tidal currents. By using the similarity theory, some experimental cochlear rotors have been developed and some approaches have been made for a series of cochlear small hydropower plants covering small heads, including conditions with zero heads for the particular cases of the coastal and tidal currents of Cephalonia and Euripus Strait

Keywords: *Archimedean Turbines, Screws, Hydrodynamics, Small hydropower, Renewable energy.*

1. INTRODUCTION

It seems that hydraulic and Archimedean technology had a very long history in Greece. It began during antiquity, 23 centuries ago, during Hellenistic time, in the technological context of Macedonian Alexandria, in the famous Library and Museum, where the spirit of Aristotle's was present, with various machines and mechanisms, gears, planetaria, celestial globes, the Antikythera Mechanism, with pumps, various mills driven by water wheels etc [1]. The oldest hydraulic machines still remaining in operation is the Archimedean screw pump; a device which pumps the water for irrigation and drainage purposes, consisting of coiled tubing with an inclined axis, able to effectively draw sufficient amounts of water. Its discovery is attributed, on the basis of numerous Greek and Latin texts, to the greater perhaps engineering and mathematical genius of antiquity and all times, Archimedes of Syracuse in the 3rd BC century. The screw pump was first mentioned by Diodorus of Sicily, Athenaeus of Naucratis, Moschion etc. The Roman engineer Vitruvius gave a detailed and informative description of the construction of an Archimedes screw in his monumental engineering project “De Architectura” and since then, the classical description of the Archimedean screw continues to contribute greatly to making the screw the most famous hydraulic device worldwide, which even today continues to dominate not only the area of the pumping and irrigation applications but in a broad theme even related with military or space propulsion applications [1, 2]. It is an ingenious pumping device which operates in a simple and elegant manner by rotating a rotor with helical inclined blades within adductor roll, whose lower end is immersed into the pumping water. Once the screw is rotated, the water moves upstream between the helical blades and the wall of the tubular chute, is transferred to the upper end of the screw device. The evolution of these spiral hydraulic screw mechanisms continues nowadays thanks to the overtime-continuous Archimedean contribution. Despite the fact that the brilliant spirit of Archimedes continues always to be present, this paper intends to give the rightful place, nowadays in Greece, in the era of transition and crisis, to the always-modern Archimedean philosophy, in order to determine the most reliable and ecological way for a very promising future low-head hydraulic sustainable development. A view of the famous Archimedean screw with eight blades, as described in Vitruvius work "De Architectura", along with a three bladed screw, and farmers using a conventional manual screw pump to irrigate their farmlands in the Nile delta of Egypt, are shown in Figure 1 [1, 2].

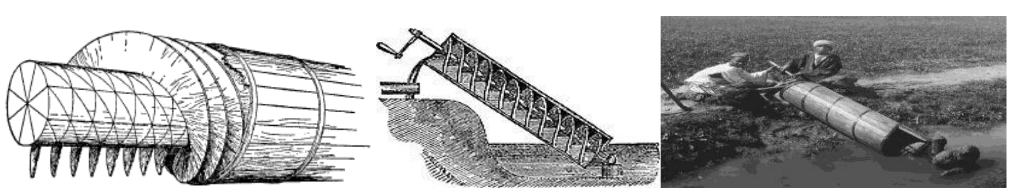

Figure 1. Depictions of Vitruvian Archimedean screw pumps.

2. TOWARDS THE ARCHIMEDEAN SCREW HYDRO PLANTS

As screw turbines are defined the non conventional hydropower turbines, based on the reversal of the Archimedean pumping operation converting into mechanical energy, under conditions of continuous flow and constant rotation, with the aid of screw rotor rotating with angular velocity ω and torque M, inclined or horizontal axis**,** using the available hydraulic energy for low head positions, even with zero disposable head, watercourses natural or artificial, large or small and the kinetic hydropower in free flow conditions, in small or large rivers, open channels, even marine and tidal currents. The inverse use of the Archimedean screw, as a kind of screw pump-turbine, is under discussion, during the last years, within the hydropower scientific community [3, 4]. The area of low head hydropower has attracted the attention of many researchers in order to use and develop new and efficient, environmental friendly Archimedean cochlear hydropower plants [5]. Archimedean small hydropower plants were installed during the last decade in Central Europe by several industrial companies, which are based on the inversion of the energy flow in their pump operation and turning the old screw pumps into new Archimedean turbines [6, 7].

The very significant untapped Archimedean hydrodynamic potential, of about 30 TWh according a recent inventory [8] the current Greek economic crisis situation and all systematic efforts relative to the hydrodynamic behaviour studies of innovative Archimedean screw turbines recovering the hydropotential of watercourses and coastal currents probably should give an increased impetus in low head hydraulic renewable energy sources. According to the present research, within ARCHIMEDES III program, entitled "Rebirth of Archimedes: contribution to hydraulic mechanics study and Archimedean cochlear waterwheels hydrodynamic behaviour, for recovering the hydraulic potential of natural and technical watercourses, maritime and tidal currents", the "Inclined and Horizontal Archimedean Cochlear Screws" could find very promising modern applications, as efficient hydraulic turbomachines. Figure 2 gives a schematic representation of an Archimedean screw turbine with inclined shaft exploiting the potential of a watercourse having a flow discharge Q and a height H.

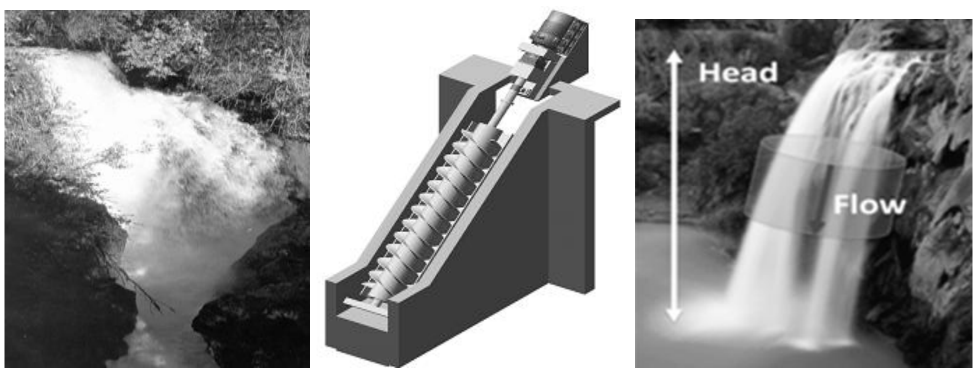

Figure 2. Schematic representation of an inclined axis Archimedean turbine.

It is known that the forced rotation of a screw turbine can be productively transformed with a suitable system to mechanical or electrical power, P=M.ω, (M: torque, ω: angular velocity). The geometric characteristics of the screw rotor are a very interesting object of dimensioning and optimization study, always in combination with computational modeling of the flow field, the hydrodynamic behavior, the function and successful performance. Despite the fact that, several hydraulic machines, as the Lafond and Banki turbines, have common origin with the hydraulic screws but fully distanced themselves from them. The screw turbines could be used as an effective recovery of the hydro-potential energy for low disposable head of natural and artificial watercourses and the kinetic energy of rivers, open channels and sea currents, presenting quite diverse geometric and hydrodynamic characteristics and particular flow field circumstances. These machines with inclined or horizontal axis bearing screw blades fully differentiated from both action and reaction turbines. In the case of inclined shaft, the screw rotor accepts directly by gravity action of water only in the downstream portion, and in horizontal axis turbine rotor is required to utilize the kinetic energy of the flowing mass. In each case the forced rotation of each screw turbine can be productively transformed with a suitable system to power. It is well known that modern conventional turbines are divided into two categories, the total attack runners or reaction and partial attack runners or action. The first is radial or mixed flow type Francis and axial flow type Kaplan, tubular, crowns, etc., with the sufficient movement of the static water pressure. The latter are characterized as turbines and the type is Pelton, Turgo, Cross-Flow or Banki, Lafond etc. In these, only a part is supplied with flow, by contributing under static pressure uniform and zero reaction to the effective transformation of energy [9]. Unlike conventional turbines, the unconventional screw turbines constitute an intermediate state, both the classical water wheels and conventional turbine action and reaction having a portion of the screw blades out of the water, as with inclined axis while in other cases as the horizontal axis of the screw turbine, the rotor being completely or partially submerged in water, in conditions of complex free surface is required to harness the kinetic energy of flowing masses.

3. BASIC PRINCIPLES OF SCREW TURBINES

Although the origins of helical rotors, that consisting the heart of the screw turbines, are lost in the depths of classical antiquity, the literature search revealed that there is no design theory or study of the hydrodynamics behavior and performance of screw turbines or no theoretical one-dimensional, two-dimensional or three-dimensional computational model simulation [10]. To this may have contributed to the predominant, but completely wrong impression that the small amount of available head from 0, 0.5m to 2.5m or 10m hydroelectric potential of natural or artificial watercourses, with flow discharges from 0.1 to $5.5m^3/s$, is technically untapped and ecological sensitive.

Consequently relatively few screw turbines are built, installed and operated in small hydropower projects. It is surprising that these minimum established screw turbines are not designed and constructed as screw turbines but as natural extensions of functional reversal of screw pumping mechanisms. The complexity of internal flows within the screw turbine presents a bold timeless, scientific, technological and computational interest. It is known that the internal flows are affected by secondary phenomena that have their headquarters in the boundary layers and interactions between blades and flow. Even the dominant role of turbulence, the role of viscosity is limited close to the walls of the screw turbines. The complex approach of the three-dimensional nature of the flow in the turbine could be achieved by superimposing / coupling two individual two-dimensional flow, based mainly of cases Wu, the surfaces S1 and S2, on a "meridian" flow and a blade- flow. Within a simple, coherent approach and calculation of the basic flow of the particular screw turbine case, adopted one-dimensional and two-dimensional calculations techniques midline flow, making approaches like "actuator disk», or even adopting coupling techniques two-dimensional flow, similar to the method Wu art, by analysis of the flow in two levels of flow type S1, S2, as in the figure 3.

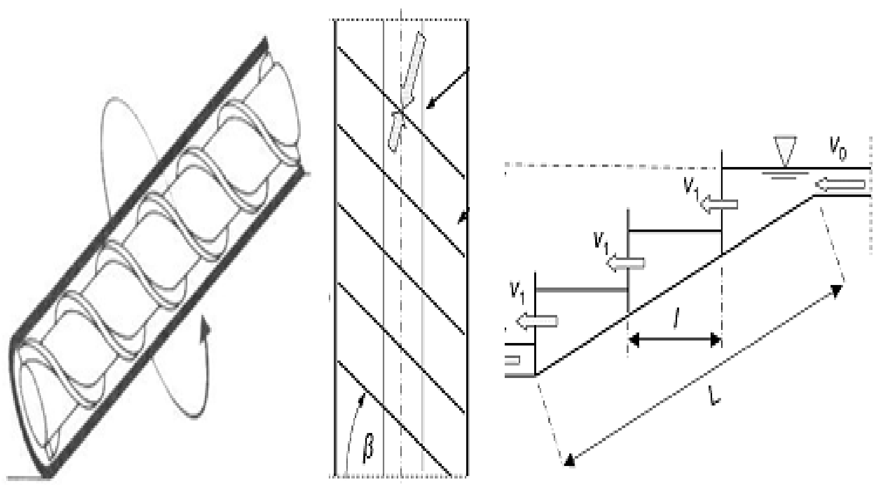

Figure 3. Schematic computational approach of a screw turbine, with «actuator disk» type, or with Wu analysis at two flow levels.

In the present work, part of the research ARCHIMEDES III, we try to study all the inclination axis screw angle cases, θ1, θ2……θn, from the zero angle ($\theta=0^o$) horizontal screw rotors, able to harness the zero head kinetic flowing potential of rivers, open channels, coastal and tidal currents, to various inclined axis screws, $0<\theta<90^o$, trying to find the optimal inclination angle, included the special case of the vertical screws ($\theta=90^o$). It is obvious that the extreme orientation cases, the horizontal and vertical axis screws, could be good only for the recuperation of the kinetic hydraulic energy. Figure 4 shows the spectrum of all the screw axis orientation cases.

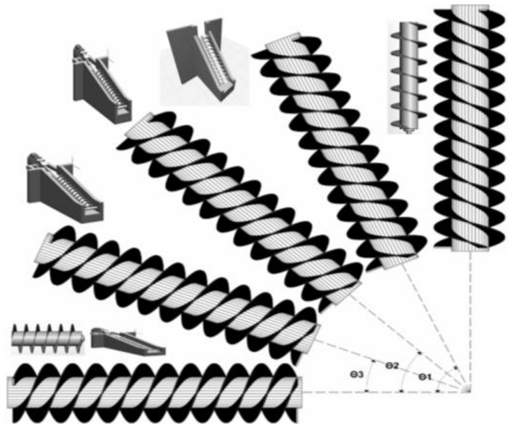

Figure 4. The spectrum of all the screw axis orientation cases.

4. SOME NEW SCREW TURBINES SIMULATORS

The screw turbine geometry, length, slope, outer diameter, inner diameter, pitch of fins, orientation angle and thickness of fins, etc. is a very interesting dimensioning, planning and determination research of nominal conditions, depending on the available head, supply and speed in order to optimize the performance of the turbine cochlear both in nominal and non-nominal conditions. Using the methodology of the similarity theory (Buckingham's p-theorem) we constructed and manufactured two experimental laboratory models, with screw rotors in transparent cylindrical adducts, which could operate in controlled flow conditions of a large laboratory open channel. The first of the two standards turbines screw was constructed in such way as to have the dual ability to be able to work as a pumping screw, while the second was solely turbine. According to the definition of the characteristics of geometrical sizes of turbines manufactured standard screw, the active length of each blade is 35cm. The screw blades step of the two experimental models is common and equal to s = 5cm, the outer diameter of the two guiding transparent cylinders is d = 7.2cm, while the diameter of the shaft is dm = 1.4 cm for the first pattern, and dm = 1.1 cm for the second standard. The number of steps is 7. In the figure 5 the gap between the blade tip and the outer cylinder is 1cm. Average construction values of the characteristics dimensionless geometrical quantities of the two manufactured experimental laboratory screw turbine models are s / d = 0.7 (1.4), dm / d = 0.2 (0.15), g / d = 0.035.

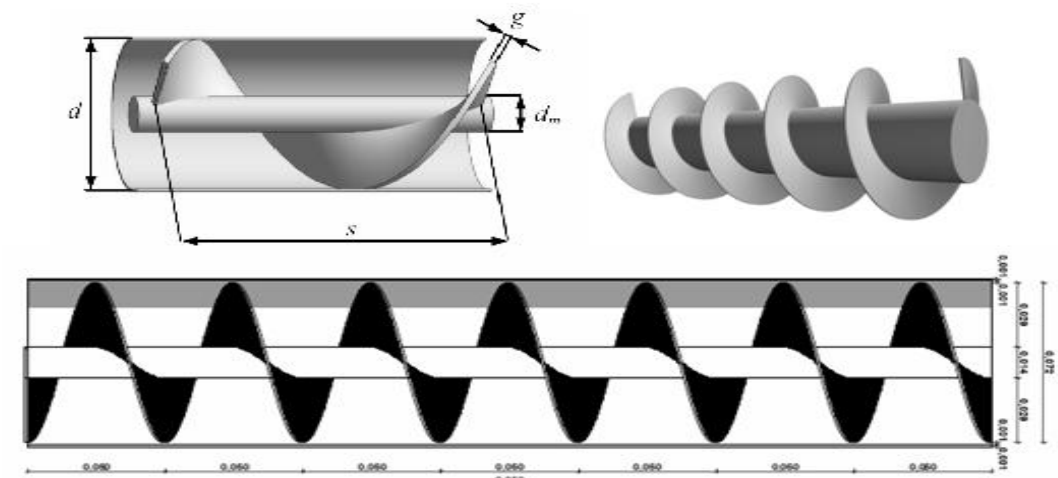

Figure 5. . Definition of geometrical features of two standard screw turbine sizes

The angle orientation of the two experimental laboratory models inclined axis within the large hydraulic channel S3/TILTING FLUME Armfield is from the 20-34 ^{o}. The channel depth is variable with a maximum of 31cm.Quite useful measurements of both the first and second standard laboratory screw turbine were made. The first measurements showed the important role of water supply and diameter of the screw rotors achieve quite remarkable efficiency levels of around 60 to 80%, making them credible alternative turbines for low head disposable. Figure 6 gives a distinctive comparative visual quote of the first and second screw turbine laboratory simulators, identifying similarities and differences, together with some of the first attempt to construct the typical laboratory screw standards.

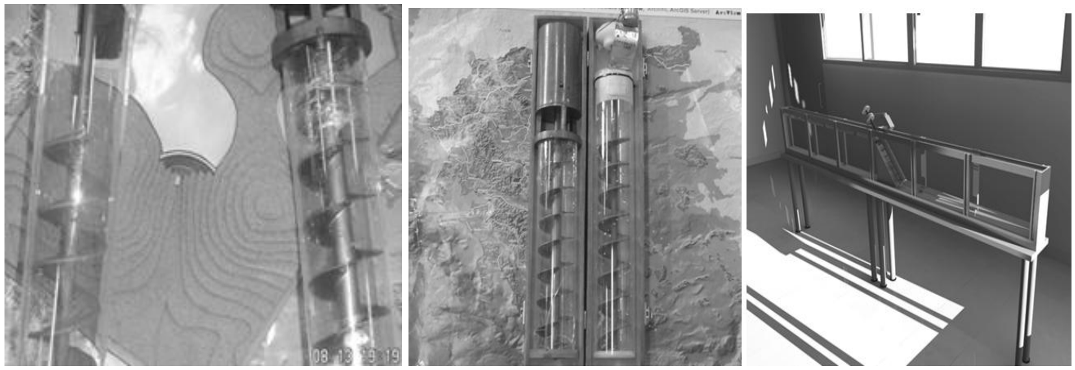

Figure 6. Laboratory screw turbine simulator models

In laboratory measurements we used an optical tachometer for measuring the rotational speed n (rev/s), one tilt sensor for measuring the inclination of the rotor axis and a vernier depth gage for the assessment of depth flow h (h = L.sin a, with L = 35 cm, the length of the screw rotor). The inner diameter of the rotor is dm, d_m = L/20 - L/25, while the outer diameter is d = 7.2 cm. The water supply Q (m^3 / s) was measured with a conventional propeller flow meter. The efficiency η = P_{out}/P_{in} , which is a function of the geometry and rotational speed n of the screw and the supply Q, calculated by determining the input power P_{in} and the output power Pout, with P_{in} (W) = Pth = ρ.g.Q.H and P_{out} (W) = T.ω = T.2.π.n, where ω is the angular velocity and T (N.m) the growing axis of rotation torque. Figure 7 shows the experimental results of the first theoretical power P_{th}, the rotational speed n (rev/s) of the screw and the applied torque T (N.m), as a function of supply Q (l/s) [8]. The efficiency η, a function of the geometry of the screw, the diameter d, the flow passing through Q, the rotation speed n, tend to obey the following correlation: η = [1-0.01125.d^2/Q].(2.n+1) / (2.n+2). The rotation speed seems to follow the correlation N (rev/s) = 0.85/ $d^{2/3}$ [11].

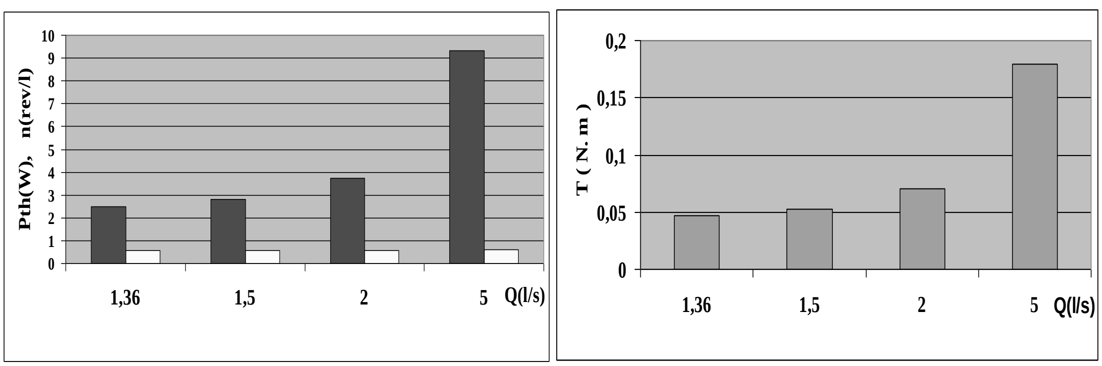

Figure 7. Measurements of power, speed and torque as a function of supply

Figure 8 presents typical experimental aspects of the operation of the first and second experimental model screw turbine, which carries a flywheel inertia and propagation speed system, within the large open channel hydraulic S3/TILTING FLUME of Armfield.

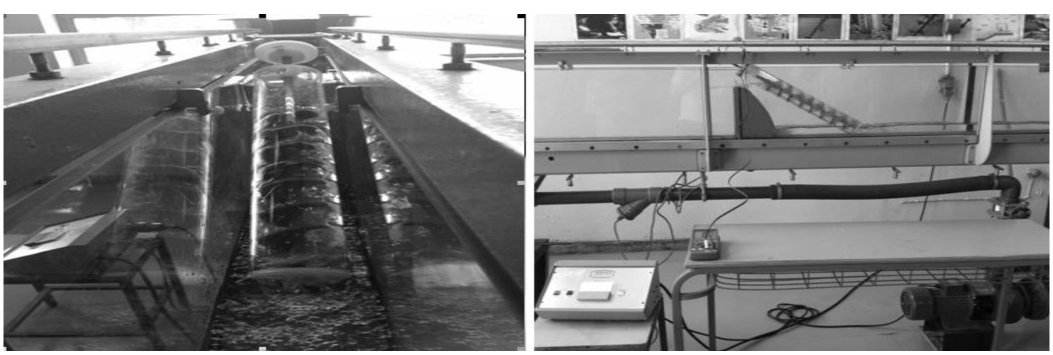

Figure 8. Aspects of screw experimental simulators in operation.

Another stand-alone small scale Archimedean hydropower plant model was actually created (figure 9) having an orientation of 26^o and a rotor with a length 21cm, a step of 3cm and a small diameter ratio $D_i/D_o=1/7$. A systematic measurement campaign started recently giving some very promising preliminary results.

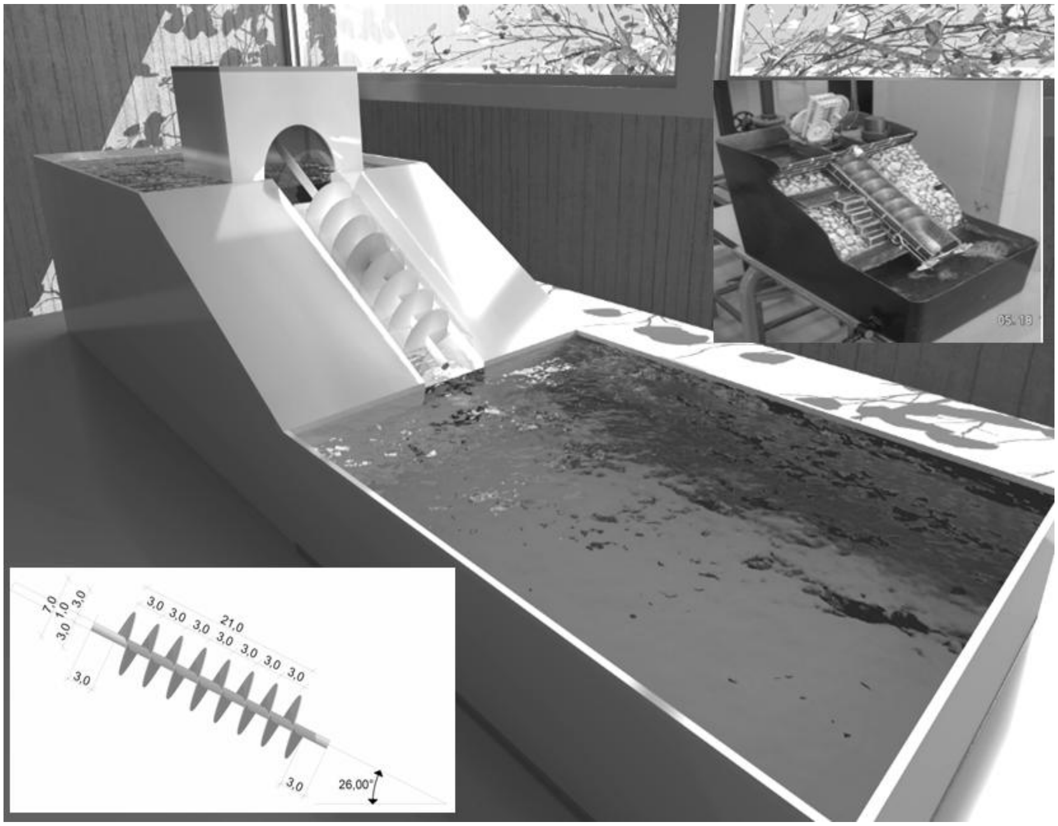

Figure 9. Representative views of the new stand-alone small scale Archimedean hydropower plant model

Besides this independent stand-alone small Archimedean hydro plant another new cochlear rotor was created by "thinking like Archimedes with a 3D printer" (figure 9). The length of this screw rotor is 30cm, the step is 3.5cm and the ratio of inner and outer diameters is D_i/D_o = 3/6=0.5 The rotor was putted in a transparent plastic tube of a diameter D=8 cm, in order to make experiences and obtain measurements in an open flume channel.

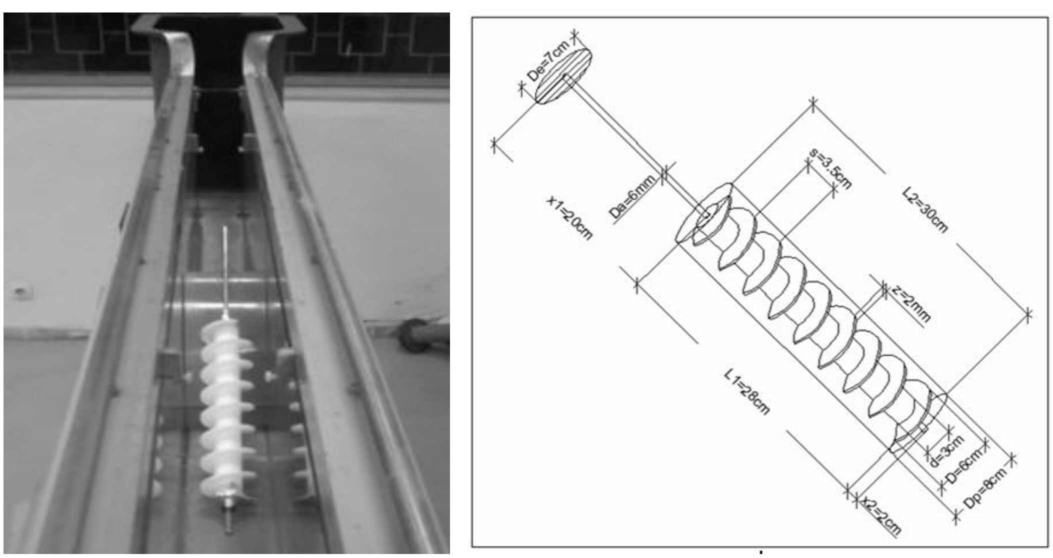

Figure 9. Two views of a new cochlear rotor created by "thinking like Archimedes with a 3D printer".

5. FROM EXPERIMENTAL SCREW SIMULATORS TO THE ARCHIMEDEAN TURBINES

The finding that the screw turbines may well be the only way to recover the hydrodynamic production of low head and also to compete economically, in a very satisfactory manner, other contractual turbines, led to the development of our first experimental results, following the hydraulic similarity theory. Based on these first experimental results, quite satisfactory estimates can arise about the hydrodynamic performance of real "potential" tubular screw small hydro stations. For a tentative low head position H=1,0m, with usable supply Q=1,2m³/s, a small hydroelectric project with tubular screw turbine diameter d=1,6m, length L=3,1m, which could be "similar to the utilized experimental simulators", the resulting power based on the laws of similarity $Q_1/Q_2=(N^2{}_1D^2{}_1)/(N^2{}_2D^2{}_2)$, $Q_1/Q_2 = (N_1D^3{}_1)/(N_2D^3{}_2)$, $P_1/P_2 = (N^3{}_1D^5{}_1)/(N^3{}_2D^5{}_2)$ and generalized Moody relationship $(1-\eta_1) / (1-\eta_2) = (D_2/D_1)^{0.25} (H_2/ H_1)^{0.1}$ assuming that they can be applied between similar turbines, with known operating characteristics and assuming that these correspond to ours similar simulators, is P = 8 KW. The similarity theory can also be adopted to evaluate the performance of Archimedean screw plants whether the screw turbines are also located in tubular water supply networks (figure 10).

Figure 10. No tubular and tubular screw turbines applications

This approach could be applied to the SWM hydroelectric power plant "Stadtbachstufe" in Isar, in Munich. SWM (Stadtwerke München GmbH/Munich City Utilities) is a German communal company, owned by the city of Munich, which offers public services for the city and the region of Munich. The company supplies electricity for more than 95% of Munich's 750.000 households. The SWM hydroelectric power plant "Stadtbachstufe" in Isar is a small Archimedean hydropower exploiting a small height of 2,80 m and a nominal water discharge of 2,50 m³/s. The diameter of the screw is 2,70 m and the length is 7,85 m. The rotation speed is 28 RPM. The estimated installed power of the plant is 50 KW. The yearly produced energy is about 400.000 KWh. The photo of figure 11 was given to us by SWM engineer D. Nicolaides during our visit in this plant [12].

Figure 11. A view of the SWM hydroelectric power plant "Stadtbachstufe", in Isar, Munich.

For another site position example, with low head H = 3,0m, usable supply Q=4m³/s, the resulting installed power of the threaded screw turbine is P = 85KW. According to the heretofore computing estimates, the low head screw turbines can be placed in series and parallel positions covering complex requirements with load 1 to 10m and water supply of 0.1 to 5.5 and also to 50 m³/s and for installed powers from 1 to 300KW. Estimates for a real indicator, if the available head is 10m, or more, and supply 2680 l / sec, with a two, or three-stage screw turbine placed "in series" could provide an installed capacity of 180KW. Following the 'similarity' logic, such a small screw turbine with an installed capacity of about 70 KW could produce annually 260.000 KWh.

6. TOWARDS INNOVATIVE ARCHIMEDEAN WATER CURRENT TURBINES

Recent ARCHIMEDES III research efforts proved, besides the Archimedean inclined axis cochlear turbines, the useful exploitation of another Archimedean screw technique, under the form of second cochlear devices, the form of Archimedean water current turbines with horizontal floating cochlear rotors. These devices harness the unexploited flowing kinetic hydraulic potential of natural streams, open channels hydraulic works, coastal and tidal currents as well. A series of floating screw rotors could be installed for recovering the hydraulic kinetic energy potential of open irrigation and water supply channels. Figure12 gives photorealistic views of a schematic floating horizontal-axis Archimedean hydro plant and two virtual representations with one cochlear rotor in Evinos River and two rotors in an irrigation channel turning with a flowing speed 1.8-2.1 m/s.

Figure 12. Photorealistic and virtual representations of floating rotors in natural or artificial watercourses

Such horizontal rotors could be tested in the entrance and exit of the natural canal of Cephalonia's strange sea river current and in Euripus Strait, subject to strong tidal currents, which reverse direction approximately four times a day. The Ionian island of Cephalonia is the site of one of the most astonishing hydrological phenomena in the world, with a seawater massive current flowing continuously into karstic substratum of the island, through sinkholes, near Argostoli's town. Cephalonia's coastal paradox constitutes a real world unique mystery [13]. The mysterious coastal seawater current reappears, after an underground route of about 15 km long, on the opposite coast of the island at brackish springs, near Sami's town. A recent measurement campaign, from May 2011 to April 2012, in Cephalonia's sea current entrance, demonstrates that mean flow speed is around 1.7-2.0 m/s. It seems that this current flow is sufficiently powerful to drive new well-designed Archimedean spiral power screws and produce valuable electricity. According to the present research a series of floating screw rotors could be installed for recovering the hydraulic kinetic tidal energy potential of Euripus Strait and Cephalonia's coastal paradox flow. Some first floating Archimedean hydro-generators models have been "virtually" examinated giving very promising preliminary results for future ARCHIMEDES III research. Figure 13 presents a general view of Cephalonia island, with its coastal paradox, and gives photorealistic views of one horizontal cochlear rotors for the energy recovering of Cephalonia's astonishing marine phenomenon [14].

Figure 13. Views of Cephalonia, with its coastal paradox and two horizontal screw rotors.

Series of such similar or different horizontal floating Archimedean energy screws could be also installed in Chalcis strait, for recovering the hydraulic kinetic energy potential of Euripus tidal channel in Aegean Sea [15]. Figure 14 gives representative photorealistic views of one and three horizontal cochlear rotors in Chalcis Strait for harnessing the hydraulic kinetic energy potential of Euripus tidal channel.

Figure 14. Photorealistic views of horizontal Archimedean rotor in Euripus Strait.

7. SEARCHING THE FIRST ARCHIMEDEAN CONCLUSIONS

The presented here contributions to the hydrodynamic behavior study of innovative cochlear screw turbines and the preliminary ARCHIMEDES III research efforts proved the very promising and very useful exploitation of two types innovative screw techniques, under the form of Archimedean inclined axis cochlear turbines and Archimedean water current turbines, harnessing the important unexploited low-head Greek hydraulic potential of watercourses and recovering the flowing kinetic energy of streams, open channels, coastal and tidal currents as well.

Hitherto laboratory measurements and calculations in the framework of the research program ARCHIMEDES III, concerning the preliminary hydrodynamic investigation of the innovative screw rotor simulators with inclined axis, tends to show that the screw turbines can be the technological basis to implement many environmentally friendly small hydro screws in a variety of positions in most small waterfalls water districts in Greece, which has a very substantial untapped hydropower potential of 30 TWh [8]. The entire research effort is ongoing and continues under the program ARCHIMEDES III, both towards deepening the further hydrodynamic investigation towards innovative screw turbines in horizontal axis at zero head conditions in order to recover the important kinetic energy potential of rivers and open channels and other unique marine and tidal currents like those of Cephalonia's coastal paradox and the Euripus Strait's tides.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

[1] A. Stergiopoulou and V. Stergiopoulos, From the old Archimedean Screw Pumps to the new Archimedean Screw Turbines for Hydropower Production in Greece, *Proceedings of the 2nd International Conference on Environmental Management, Engineering, Planning & Economics (CEMEPE 2009),* Mykonos, (2009).

[2] A. Stergiopoulou, V. Stergiopoulos and E. Kalkani, A brief Archimedean history: from ancient spiral screws to modern Archimedean hydropower energy tools, *Proceedings of the eRA-5 International Conference* , Athens, (2010).

[3] G. Müller G. and J. Senior, Simplified theory of Archimedean screws, *Journal of Hydraulic Research 47 (5) 666-669,* (2009)

[4] D. Nuernbergk and C. Rorres, An Analytical Model for the Water Inflow of an Archimedes Screw Used in Hydropower Generation, *ASCE Journal of Hydraulic Engineering, 23 July 2012*

[5] A. Stergiopoulou, V. Stergiopoulos and E. Kalkani, Back to the Future: Rediscovering the Archimedean Screws, *Proceedings of the “Third International Conference on Environmental Management, Engineering, Planning and Economics (CEMEPE 2011) & SECOTOX Conference*, Skiathos, (2011).

[6] B. Pelikan and A. Lashofer, Verbesserung Der Strömungseigenschaften Sowie Planungs-Und Betriebsoptimierung Von Wasserkraftschnecken (Flow Characteristics Improvement and Optimization of Water Screw Turbines), *Research Project, BOKU University, Vienna, (in German),* (2012).

[7] P. K. Kantert, Praxishandbuch Schneckenpumpe, *Hirthammer Verlag 2008, ISBN 978-3-88721-202-5.*, (2008)

[8] A. Stergiopoulou and V. Stergiopoulos, Quo Vadis Archimedean Turbines Nowadays in Greece, in the Era of Transition?, *Journal of Environmental Science and Engineering, A 1, 499-509*, (2012).

[9] European Small Hydropower Association, , A Layman's Guidebook on How to Develop a Small Hydro Site, *ESHA.* (1998)

[10] C. Rorres, The Turn of the Screw: Optimal Design of an Archimedes Screw, Journal of Hydraulic Engineering, *Journal of Hydraulic Engineering,* 126 (1), 72-80, (2000).

[11] A. Stergiopoulou, V. Stergiopoulos and E. Kalkani, Back to the Future: Rediscovering the Archimedean Screws as Modern Turbines for Harnessing Greek Small Hydropower Potential, *Fresenius Environmental Bulletin, PSP Volume 22 – No 6a,* (2013).

[12] D.Nikolaides, *Visit to the SWM hydroelectric power plant “Stadtbachstufe” in Isar, (personal communication and visit),* Munich, (2012).

[13] A. Stergiopoulou and V. Stergiopoulos, The paradox of coastal cross flow in Cephalonia island, *Proceedings of the 6th International Symposium on Environmental Hydraulics*, Athens, (2010).

[14] V. Stergiopoulos, Un paradoxe mondial de courant côtier transversal : La mystérieuse rivière maritime de l’île de Céphalonie de la Mer Ionienne, *Lecture/Conference de l’ ENS Cachan-Bretagne, Rennes,* 2 Mai 2013, *(in French)*, (2013).

[15] V. Stergiopoulos, Un paradoxe mondial de courant côtier transversal : La mystérieuse rivière maritime de l’île de Céphalonie de la Mer Ionienne, « Phénomène des marées du détroit de l’Euripe dans la Mer Egée, *Lecture/Conference de l’ ENS Cachan-Bretagne, Rennes,* 2 Mai 2013, *(in French),* (2013).