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Design and Development of a Spiral Tube Water Wheel Pumping System: A Review

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ABSTRACT

This paper provides an overview of the ancient evolution, design and development of different types of spiral tube water wheel pumping system (STWWPS). It has always been a challenge to lift water and carry it to some other location for executing meaningful work, making use of the alternative sources of power. Several kinds of non-conventional energy sources and techniques have been tried. Each one is having its own merits and demerits. Making use of the kinetic energy of flowing water can be achieved through different kinds of water wheel. Spiral tube powered by kinetic energy of flowing water has been utilized for lifting and carrying water for irrigation and other purposes, contributing to the replacement of conventional diesel and electric power sources. These conventional sources are expensive (Diesel) and often unreliable in rural areas (Electricity). This review paper examines the design, development, and performance evaluation of various spiral tube pumping systems, including single, double, multilayer, pedal type, four scoop type, and multi-purpose models. It examines the load torque, power, efficiency, and stress analysis of shaft and bearing, and the impact of rotational speed, submerged ratio, and number of spiral pipes on the performance of the pumping system. The working principle allows these pumps to create a column of water within its coil that alternatively the air which is compressed as it moves towards the center of wheel. These pumps not only save electricity and diesel cost but the maintenance cost is also low apart from contributing to the clean environment.

Keywords: *Lifting water, Water wheel pumping system, Spiral tube, Kinetic energy, Revolving wheel, Compressed air, Floating type, Discharge, Delivery head.*

INTRODUCTION

The crisis of energy is worsening day by day due to the gradual depletion of fossil fuels in the global market. Shortage of fossil fuels can become a big problem for the next generation. This calls for finding new sources of energy for our future generation, and renewable energy resources are the best solution for future power generation. Hydropower is of renewable energy source that can generate power as well as pump water into higher positions. Hydropower energy is one of the most potential energies among the other interesting energy such as solar, wind, fossil, and geothermal energy systems. In historical background, hydropower started with the hardwood water wheel. Water wheels have historically been prominent in capturing the energy of flowing bodies of water for irrigation & electricity purposes. In India, it is an age-old practice to use the ITK (indigenous technical knowledge) "*Tera* (Counter Poise Lift)" and "Rahat" systems for lifting water. This system is for lifting water from the source of the well and surface water through animal and human power. This system is operated by an individual and continuously rotates the plank. The water gets collected in the scoop and then water is discharged onto the field. Both systems are made from locally available wood material. *Tera* system involves manpower for operation, which is costly, however; the spiral tube pumping system works on the principle of kinetic energy, which may eliminate the manpower provided if flowing water is available at site specific condition. The spiral tube waterwheel was invented by Archimedes (287 BC – 212 BC) and had a name "Archimedes Snail Pump". It was used for irrigation and usually powered by humans or horses. A tube was wrapped around a pole, which was then rotated and run with axis of rotation inclined [1]. A similar pump 'The Archimedean Screw' applied the same principles of operation was invented about 1746 by Andreas wirtz, a pewter of Zurich and called by him a "spiral pump". This pump is remarkably simple, has no valve, operates down to very low rotational speed, and produces a head of water many times its diameter [2], [3].

The spiral water wheel pump system, as per its name, includes water wheel and tubes, a wheel on which the spiral tube is mounted, and it rotates due to force of water flow which acts on the blade of wheel. Water enters from the inlet side and because of rotation of wheel, the water moves spirally inside the tube. The water passing through the tube flowing toward the center of

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the wheel consists of a hollow axel which works as a discharge outlet. Water is carried out by adopting the several methods for spiral water wheel pump could also be useful for carrying the water without disturbing the side bund of canal and stream [4]. This pump is fixed with wheel, when the water is flowing inside the tube, wheel is rotated and at the same time spiral tubes also rotated it-self. The water wheel revolves, when water passes around it. At every revolution, water inlet dips into water and takes water into the tube. Maximum water passes through the spiral tube followed by a core of air, when the wheel rotates. A new core of water is formed on every rotation and this phenomenon happens continuously. A wheel has to be submerged 1/3 of its total diameter so it can take maximum possible amount of water [5]. The water wheel system depends on the kinetic energy of flowing water. When the flowing of water is directly acting on the blade it causes water to strike on the blade and the blade rotates continuously in the direction of flowing water. A pumping system powered by kinetic energy of water from nearby nallah can be a cheap, efficient and precise way of delivering water to nearby farm pond/open well. The pumping system is simple to develop, install, operate and very much cater to the need of rural remote area. It may be suitable for un-electrified as well as unreliable electric supply area provided suitable site conditions are available. The major components of spiral tube water wheel pumping system include rim, inlet valve, housing, flexible pipe, bearing, T-joint etc [6] as show in (**Fig. 1**). This study aims to describe the design of different type of spiral tube water wheel. Many researchers consider that the coil pump and spiral tube pump are same [7], [8] and they reported that cost-effective pumps are a top research priority worldwide. The system can be built out of available materials by local craftsmen and can produce two types of stream driven pump, first was coil pump and second was spiral pump. The coil pump and spiral pump works on the same principle, but designs differ significantly. In the coil pump, flexible tubing is wound concentrically around a drum or floating framework. A simpler inclined coil pump with an internal coil for low head applications also exists as shown in (**Fig. 2**). The second stream driven spiral pump, invented originally in 1746 by H.A. Wirtz and re-invented by [9] pump consists of a flexible plastic hose coiled spirally on the same axis and plane, so that each loop of the hose differs in diameter from the next, and the whole device resembles a large wheel with the axis parallel to the water surface. The large diameter of the pump makes hand-turning easy during decreased stream flow. To increase water intake into the pump, and therefore the efficiency, scoop has to be attached. At the end the hose leads into the rotating axle, and by means of a water and pressure-tight swivel, the water moves into the stationary water delivery pipe as shown (**Fig. 3**).

DESIGN OF SPIRAL-TYPE WATER WHEEL

While designing of water wheel, the first step is to measure the power potential of the stream. It can depend on the amount and velocity of water flow. Designing a water wheel needs to consider various factors, like details information about dimension, size, and shape of components, knowledge of the properties of the materials and their behaviour under working condition. Some of important characteristics of materials are strength, durability, flexibility, weight, resistance to heat and corrosion, ability to cast, machinability etc. design any machine part for from the size, it is necessary to know the forces which the part must sustain. It is also important to anticipate any suddenly applied or impact load which may cause failure. The first record of water wheels dates back to ancient Greece. Over the next several centuries the technology spread all over the world. The process of arriving at the design of the modern Francis runner lasted from 1848 to approximately 1920. Though the modern Francis runner has little resemblance to the original turbines designed by James B. Francis in 1848, it became known as the Francis turbine around 1920, in honour of his many contributions to hydraulic engineering analysis and design. The modern Francis turbine is the most widely used turbine designed today, particularly for medium head and large flow rate situations, and can achieve over 95% efficiency [10]. The waterwheel is one of the oldest hydraulic machines known to humankind and has been in use since antiquity. Originally built of wood, the availability of new materials, namely wrought iron, and the increasing demand for mechanical power during the industrial revolution led, in combination with the development of hydraulic engineering, to the rational design of waterwheels, resulting in much increased performance and efficiency [11].

An undershot waterwheel was designed for water pumping and to analyze stress on the shaft. The undershot waterwheel system was employed in Man-Eating canal at Meiktila Township, Myanmar. The wheel is made from mild steel material and with a diameter of 6.1 m and width of 1.22 m, and the rotational speed is around 2.3 rpm at inlet velocity 0.762 m/s. In this design, load torque, driving or flow torque, power and efficiency, shaft and bearing design are briefly considered. The analysis of shaft strength was discussed while the design discharge from the measurement was 1.274 m^3/sec [12]. The design of the water wheel was dominated by the requirement for a geometry which would minimize losses and retain the water. Theoretical output power of energy has been calculated for arranging water flow and a graph has been plotted using the relevant values [13].

[14] developed a spiral tube water wheel pumping system (STWWPS) which consisted of hollow axel pipe, supported by hosing bearings which are mounted on stand and float. The total weight of the pumping system is bearded by float. The system developed is having two inlets which are placed in same line and the angle between them is 180-degree. Both the inlets are connected in a single pipeline through housing pipe. The principle that allows is the alternative water and air column in the coil. Air being compressible in nature increase the delivery of water. The testing of spiral tube water wheel was evaluated at different delivery head and different horizontal distance for carrying water as both of these were affecting the discharge very much as shown in (**Fig. 8**). The result showed that the STWWPS gave a discharge of 0.59 to 0.44 *lps* at delivery head is 4.14 to 4.83 m and horizontal distance of carrying water 3to 10 m. The STWWPS can give a discharge of 55296 *lpd* at velocity 2 m/s, water depth of 1 m and lifting head of 4.28 m and carrying distance of 3 mas shown in (**Fig. 4**).

A water wheel and coil pump were designed in Chirundu, Zambia for a municipal water use, which consisted of three types of different spiral pumps. The first coil pump built in Chirundu was constructed of wood and coated with several layers of water-proof paint. This pump involves 8-ft rolled steel shaft, paddle, four 55-gallon drum for floating platform and PVC coil pipe. The second coil pump that re-use the wheel and shaft and included hydrodynamic pontoons made entirely of 1.2 mm thick steel. The third version of the pump also utilized a 5-cm diameter galvanized iron pipe for the wheel axle. To improve balance and increase the pump discharge, each side of the wheel had 13 coils. At 7 rpm, it discharges 36 *lpm* to 6500-L storage tanks. A study that concludes that the pump used for irrigation and made from locally available material. It is observed that the water wheel pump gave 30 liter of water per minute at a safe gathering area 30 m onshore and at an elevation of 10 m above the river. The coil pump has the potential to provide crop irrigation for many neighboring communities. For this to be a sustainable technology, the pump's rotating joint must be carefully fabricated [15] as shown in (**Fig. 5**).

Analysis of spiral water wheel pump omits the use of conventional fuel sources and serves as a clean energy pump that could not only lifts water at certain height but can also provide discharge at certain height. Earlier a spiral pump was developed and still in use, made of PVC tube that were coiled around on a wheel frame. The methodology involves the use of four spiral tube scoops that were attached in a single frame condition each scoop been at 90-degree angle to one another and this arrangement was finally connected to a single common outlet rotary union mounted about vertical axis. A study concludes that the four scooped spiral water tests demonstrate the excellent potential of this preindustrial concept when experimented with a modified scaled-down testing apparatus that allows us to precisely control variables and accurately measure experimental result. The four scoops concept has appeared as a boon to the spiral pump efficiency, as reduces the chances of empty rotations of tubes and transfers more water in four continuous scoops [8] as shown in (**Fig. 6**). The turbine developed has an outer diameter of 2m with 18 pieces of straight blade prepared from the materials from aluminum on the side of the turbine wall embedded the spiral tube pump with 5 coils was designed to operate concurrently with electrical generation. The height of water resources varied by controlling the opening of sluice gates to find out the potential. As combination (water turbine with spiral pump), the turbine uses have led to increase the needs of water flow rate as energy resources in irrigation system. Throughout study the maximum electric voltage achievements was 125 volts. At the same time, the pump discharges the water with 9 liter per minute. These results provide sufficient supply of press water and electrical power for a family at contiguous area [16]as shown in (**Fig. 7**).

Another study was concerned with the design and testing of multi layers coil pump to obtain the pump performance under different design parameters. These include method of winding the hose around the drum in multi-layer, inlet and outlet position, hose inner diameter, drum diameter. For this purpose, a coil pump was designed, contracted and tested. The experimental results showed that the three-layers, coil pump has better performance than single and two-layer pumps. A study that concludes using multi-layers coil pump with the pump intake placed at the top end of the upper layer improves the pump performance and gives higher discharge. If increase drum diameter and hose diameter lead to better coil pump performance [3]. The floating water wheel is a rotating machine, which converts kinetic energy and positional energies into useful power and floats according to the level of the available stream. The water wheel and blades or buckets were the main components of the floating water wheel. In some cases, the wheel is mounted perpendicular to vertical axis but most commonly, the wheel is mounted perpendicular to horizontal axis. Mounting type depends on the type of application [17]. The traditional water wheel with simple construction couple with a basic concept of technology can be utilized as a renewable and sustainable rural energy system. The water wheel may also have a big economic impact on the rural economy, increasing the productivity of the rice field [18]. Several scientists/engineers have adopted different criteria in their pumping system. The summary of it is presented in **Table1.**

Factor Affecting Performance of Spiral Tube Pumping System

Effect of various parameter viz. rotational speed, number of coil and submerge ratio on the performance of spiral tube pump have been described herein:

Effect of the pump rotational speed

Increasing the pump rotational speed increases water flow rate until it reaches its maximum depending on the working submerged ratio, then the discharge decreases by increasing the rotational speed. Meanwhile slight changes are obtained for the pump static head when the pump rotational speed changes. The number of pump coils is also one of most effective parameters on the coil pump performance. Increasing number of coils increases the pump head while pump discharge is nearly constant [1].

Effects of changing the number of coils

The water pumps itself consist of a poly type tube arranged so that it forms a spiral fixed either on the sides of the belt so that it fits within the pedals of the wheel. In most operating wheels two spiral tube pump is used, placed within the wheel in horizontally opposed positions. Water enters the spiral tube through an enlarged pipe which acts as a water collector. The height to which water can be pumped depend on the number of coils in the spiral tube: As an example, a 2-meter diameter wheel can pump water up to approximately 8 meters with 6 complete coils, the same wheel being able to pump up to 6 meter 4 complete coils and 4 meters with 6 compete coils. For larger wheels where the diameter of the wheel an approximation can be made by multiply the diameter of the wheel by number of coils. A 4-meter diameter wheel with 3 coils should be able to pump water up to a height of 12 meter. The volume of water pumped depends on the capacity of the spiral tube [9].

Effects of the submerged ratio

[1] Determined the range of submerged ratios and divided it into two groups. The first group is ranging from 15% to 100% submergence. More details are required to obtain a clear performance, so the second group is from 85% to 100% is performed to identify the submerged ratio effects on the pump performance. In this type of pump, the pumping action is obtained due to the presence of air with water within the coiled tube. As the pump is partially immersed, air enters and is blocked between two successive water amounts in the pump coils. When coil pump rotates air pressure increases due to water column, the air act like compression spring creating the pumping action. The compressibility effect as well as the low specific gravity of air concerning water play dominant effects on the coil pump operation.

Firstly, effect of Submerged Ratio, in the Range from 15% to 100% was examined. The submerged ratio, Sr, increases from 15% up to 85%, and the water discharge increases. Meanwhile, for Sr = 100% there is no flow Q = 0. This behaviour can be explained as follows: For this type of pump, the pumping action is obtained due to the presence of air with water within the coiled tube. This explains why there is no pumping action when the submerged ratio is zero, Sr = 0, as well as when S_r = 100%. In the first case, Sr = 0, there is no water, and the coil tube is completely filled with air. While in the second case Sr = 100% the coil tube is filled with water. The presence of air with water for submerged ratio 0 < S_r< 100% gives the coil pump its pumping action while it operates. When the pump is running at a certain rotational speed until the static head reaches its maximum value and that occurs when a fully developed water column is formed in the transparent vertical flexible delivery pipe after air escapes from the delivery pipe and a reverse flow occurs through the pump inlet bore. Significantly, the static head changes slightly by changing rotational speed. The static head increases as the submerged ratio up to 15%, while from 15% to 75% it is nearly constant and then decreases drastically to zero when the submerged ratio reaches 100%.

Secondly, the effect of the Submerged Ratio, (SR), in the Range from 85% to 100% was examined. It was done to obtain a clear investigation for the pump performance in the range of submerged ratio (SR), from 85% to 100%. It is configured that, in the case of SR = 100%, the pump flow rate and static head are zero due to the absence of air which causes the pumping action. Consequently, experiments were carried out to study the pump behavior due to increasing the submerged ratio, step by step, from 85% to 100% in the same range of the rotational speeds. For a certain value of rotational speed, N, as the submerged ratio increases the water flow rate increases for all the submerged ratio, S_r, in the range from 85% to 94.25%. When the submerged ratio increases above 94.25% the flow rate continues to increase to a maximum value for speeds lower than 59.6 rpm, the maximum operating speed presented, before the flow rate decreases to zero. As a submerged ratio, S_r increases in range from 96.9 % to 100% the maximum speed at which the maximum flow rate occurs decreases as the submerged ratio increases. Finally, the flow rate reaches zero value for all speeds at S_{rs} = 100% due to the absence of air with water inside the coil tube pump.

CONCLUSION

Several scientists/engineers have worked on different aspects of spiral tube pumping systems across the globe. The study includes aspects like; load, torque, stress, working head, discharge, kinetic energy of flowing water, rotational speed, submergence ratio, and number of coils in the system. Increasing the pump rotational speed as well as the submerged ratio has a minor effect. Fully submerged and zero submerged, both conditions lead to zero discharge. The most important for the efficient operation of such a system is a favorable site-specific condition. The system has its merits for being low cost as well as low and easy maintenance. The system is very suitable for remote rural unelectrified areas provided regular stream flow conditions exist.

Figure 1 Single Layer Spiral Pump

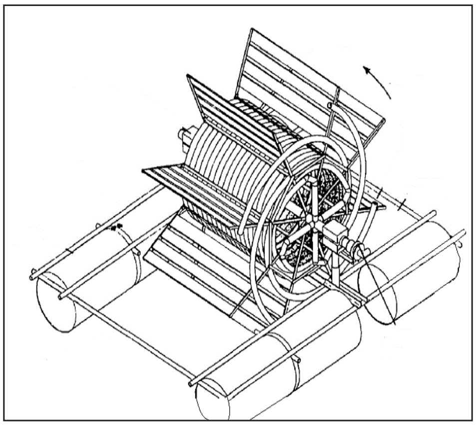

Figure 2 Combine Coil & 4 Scoop Spiral Pump

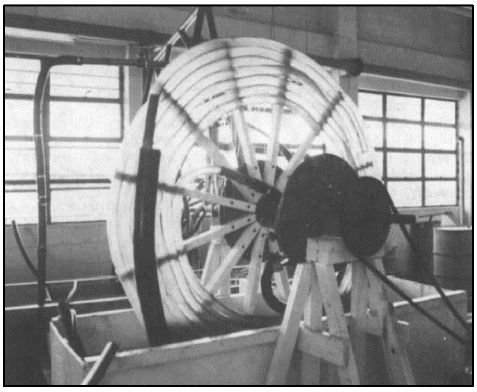

Figure 3 Morgan Spiral pump Lab test

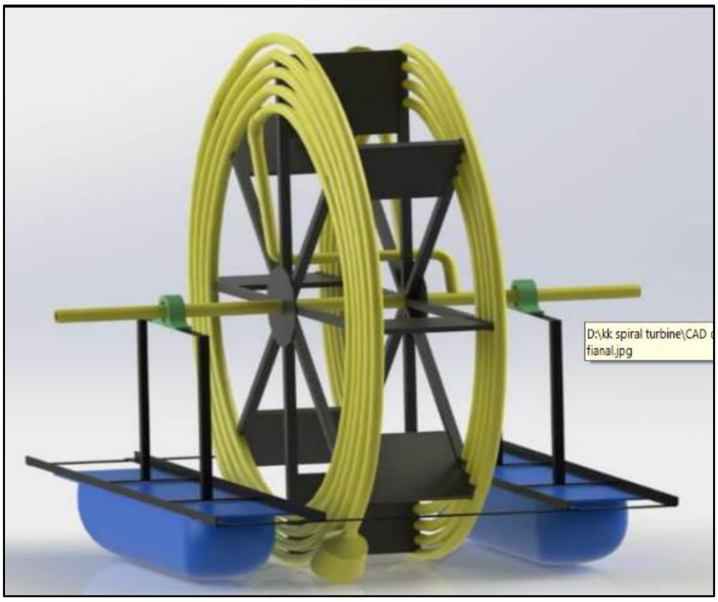

Figure 4 Double Layer Spiral Pump

Figure 5 Municiple Use Spiral Pump

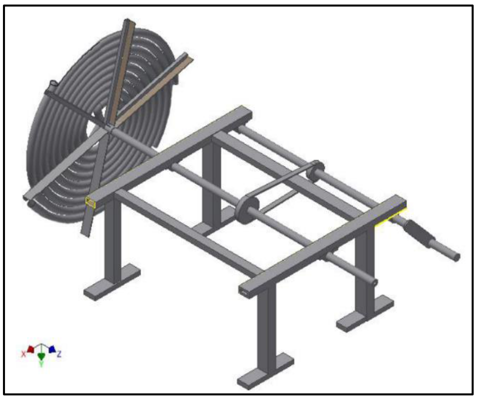

Figure 6 Four Scoop Spiral Tube

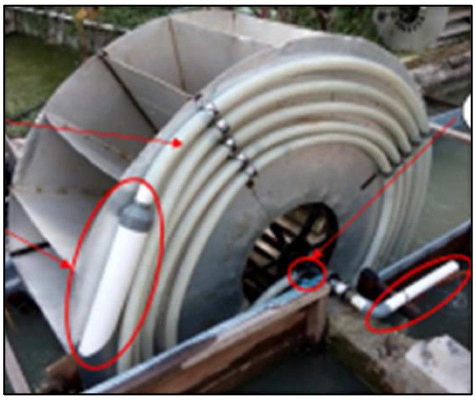

Figure 7 Combine turbine &Spiral tube

Figure 8 Testing Spiral Tube Pump

Table 1 Summary of various criteria adopted by different scientists/engineers in pumping system.

S. No.	Scientist/ Engineer	Type	Materials	Rpm	Lifting (feet)	Discharge (lph)	Origin
1	Mills (1984)	Coil tube pump	Angle Iron, PVC	9	40	-	-
2	Morgan (1984)	Spirally coil pump	Wood, Mild Steel, PVC	4.21	26	3697	Zimbabwe
3	Naegal*et al.* (1992)	Coil and Four scoop spiral	Mild Steel, PVC	-	16	-	Philippines
4	Kumar, F.& Sinha (2020)	Single Layer spiral pump	Mild Steel, PVC pipe	29	1.6	694.8	India
5	Kamalkant & Sinha (2022)	Double layer, Floating type	Angle Iron, PVC pipe	15	5.1	2124	India
6	Tomson *et al.* (2011)	Municipal use spiral pump	Mild Steel, PVC	7	32	1800	Zambia
7	Kassab *et al.* (2005)	Multi-layer spiral pump	Plastic Drum, PVC	33	16	408	Egypt
8	Dubey & Aarya (2016)	Four Scoop Water Wheel	Plywood and PVC pipe	45	16	144	India
9	Deshpande *et al.* (2012)	Horizontal Spiral tube	PVC Pipe, Mild Steel	21	5.2	360	India
10	Waghmare *et al.* (2018)	Manually operated Spiral	M. Steel, PVC Pipe	45	13.1	108	India
11	Asral *et al.* (2017)	Combine turbine & Spiral pump	Aluminum, PVC, Polyester	4.5	2.6	960	Indonesia
12	Mishra *et al.* (2016)	Pedal-operated spiral pump	Steel, PVC	30	50	723	India
13	Kyaw *et al.* (2014)	Undershot water wheel	Mild Steel	2.3	19.8	10000	Myanmar

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