Identification of Archimedes Screw Turbine for Efficient Conversion of Traditional Water Mills (Gharats) into Micro Hydro-power Stations in Western Himalayan Regions of India: An Experimental Analysis

Kamal Kashyap*, Robin Thakur *, Sunil Kumar**, Rajkumar*

School of Mechanical and Civil Engineering, Shoolini University, Solan, (HP), India

* School of Mechanical and Civil Engineering, Shoolini University, Solan (HP) India

**School of Electrical and Computer Science Engineering, Shoolini University, Solan (HP) India

* School of Mechanical and Civil Engineering, Shoolini University, Solan (HP) India

(kamal.maximus23@gmail.com, robinthakur@shooliniuniversity.com, reachtome.sunil@gmail.com,raj.me@shooliniuniversity.com)

Received: 15.07.2020 Accepted:14.08.2020

Abstract- The abundant sources of low head water streams in the Western Himalayan region create huge potential in terms of micro-hydro power generation capability, and the existing Gharats (Traditional Watermills) that were used previously for grinding flour provides an already built plant for the electricity generation. The Archimedes screw turbine is being explored all around the world as one of the best candidates for efficient electricity generation at low head and low flow rate sites. But there is a lack of research in identifying the best screw configuration for achieving maximum output power and efficiency at such low head and low flow rate sites. The experimental analysis conducted here reveals that the screw angle ranges from 20^{o} to 25^{o} with flow rate below 1.5 L/s increased the efficiency of the Archimedes Screw Turbine to around 90%. For better performance and to reduce the overflow losses the RPM of the turbine kept constant. The experimental analysis showed that Archimedes Screw Turbine can produce a humungous amount of power when implemented at 500,000 traditional water mills and easily support the adverse power requirement of the country in a cost-effective manner.

Keywords Archimedes Screw, traditional watermills (Gharats), RPM, flow rate.

Nomenclature

$A_{orifice}$	Orifice Plate Area
A_{pipe}	Pipe Area
Br_{dia}	Brake Diameter
$C_{discharge}$	Coefficient of Discharge
Dia_{inner}	Inner Diameter Turbine
Dia_{out}	Outer Diameter Turbine
$D_{orifice}$	Diameter of Orifice Plate
D_{pipe}	Diameter of Pipe
Dia_{rope}	Rope Diameter
F_{rate}	Flow Rate
g	Gravitational Constant
H_{ead}	Head
L_{oad}	Load
L_{screw}	Length of Screw
n_r	Revolution Per Minute
$Powr_{in}$	Input Hydraulic Power
$Powr_{out}$	Power Generated
P_{itch}	Pitch of Turbine
Re_{adius}	Equivalent Radius
Sc_{angle}	Screw Tilt Angle
S_{time}	Time Taken to Fill Water
t_{orq}	Torque
W_{fill}	Water Filled
Q_d	Discharge
η_e	Electrical Efficiency of Turbine
η_{th}	Theoretical Efficiency of Turbine
ρ_w	Density of Water

Abbreviations

AST	Archimedes Screw Turbine
TWh	Terawatt-hour
MW	Mega Watt
GW	Gigawatt
kW	Kilo Watt
RPM	Revolution Per Minute

1. Introduction

A huge number of traditional watermills (Gharats) mainly in the Western Himalayan region of India (approximately 500,000), have the capacity to harness a total of 2500 MW/hour or 40 million units with the aggregate earning of Rs 1200 million per hour. But this potential is almost completely unexplored in the region. The adoption of the Archimedes Screw Turbine in the European countries at an extensive level [1]. It is time for this region in India to efficiently utilize its water resources to generate electricity for sustaining the growing population of the region as well as the country as a whole[2][3].As electricity plays an important role in our lives it is very important to see new feasibilities to generate electricity [4][5][6].The benefits of using the Archimedes screw turbine have been highlighted by various researchers including [1][7] and it is evident that at low head and low flow rate conditions, these turbines work most efficiently. Though, it will be of great importance if all the parameters of the Archimedes Screw Turbine and their effect on efficiency are determined [8]. Here in this research efforts have been made to identify various internal and external parameters of the screw turbine that can affect the efficiency. The best configuration of parameters and screw configuration are to be proposed for the implementation at traditional mills for electricity generation. An experimental analysis along with the theoretical analysis has been performed in the research to come on a conclusive proposal.

2. Literature review

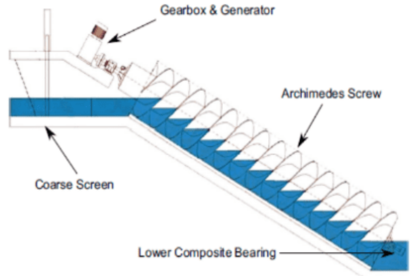
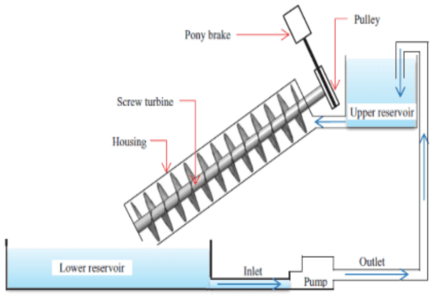
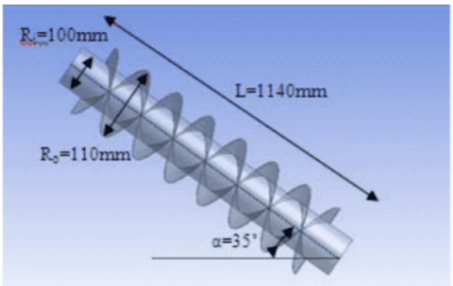
In India, at Indore (Kabitkhedi) micro-hydropower plant implemented is completely based on the Archimedes screw turbine. This micro-hydro power plant is a renewable energy power plant that is completely environment-friendly, very easy to operate and the operational cost is also less [9]. As per the survey carried out at the plant site, it was identified that the hydraulic potency of the seepage water is around 29.49 kW. Based on the results derived from a micro hydropower plant which is completely based on the Archimedes screw turbine, A micro hydropower plant has been planned for this location [10]. The power plant planned is expected to have a practical power of 19.5 kW based on a flow rate of 0.6 m3/s and a head height of 5m. The turbine that will be used in the power plant will be a mixed flow Archimedean turbine. The results derived clearly states that there is a substantial potential for the generation of electricity from the water industry [11][12]. Various studies in the past on the Archimedean screw turbine have failed to consider some of the key complexities like turbine efficiency and dissimilarities in water flow [13]. It is necessary that further research is carried out to identify the risks and long-term reliability of installations.

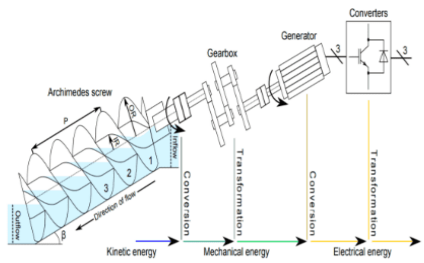
Screw turbines can be used to extract the potential energy that can be developed with the help of small rivers or irrigations. The Archimedean Screw turbine is most suitable and advantageous because of its low head and being fish-friendly i.e. fishes can passes through it easily without any harm [14]. To understand the performance of the screw turbine in an ultra-low head hydropower plant an experiment was conducted by Erinofiardi et.al [15]. In this experiment, the screw turbine having a diameter of 142 mm was taken. The flow rate of the water was about 1.2 l/s with the head of around 0.25 m. The power that is produced is 1.4 W maximum, efficiency was 49% and the angle of inclination was 22^o. For the development of the apparatus for screw turbines, locally available material was used [16]. The experiment has revealed that the screw turbine has shown great results and potential when it is used in association with the low head micro-hydro. Various performance tests were performed based on the different angles of inclination and the result data was recorded [17]. The results showed that when the angle of inclination was lowest the efficiency was highest. This has also opened doors for future research where other parameters such as pitch, number of blades, etc. can be considered. An investigation will also be required to be carried out in association with any leakage and losses as notified by Rohmer et.al [18] and only after considering all the parameters the proposed model should be tested where a full-size turbine is used.

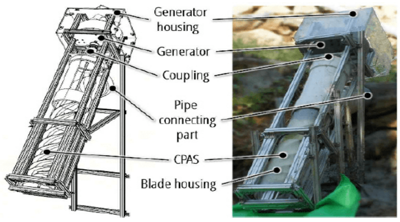
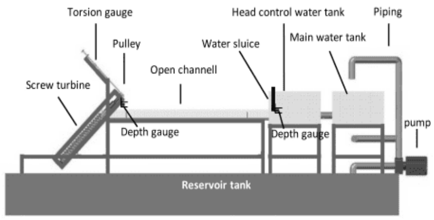
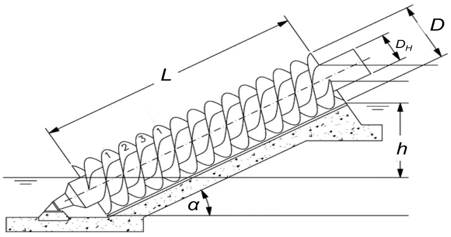
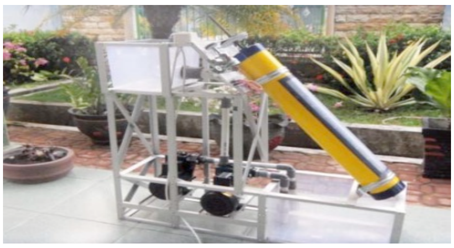
According to Yulistiyanto et.al [19] renewable energy sources used for mini/micro hydro usually exploit the potential energy that is produced by the water flow and is used to convert it into electrical energy with the utilization of turbine, generator, certain head and a specific discharge[20]. It has been identified that in many rivers the average water resource potential has low head and the discharge is large [21]. From this, it can be derived that the construction of a low or a very low head turbine is very beneficial. High flow rate of water and low head are used by the screw turbines so that torque and rotation can be generated as mechanical energy [22]. Some of the advantages that are offered by the screw turbine are that it is easy to install and construct, it is environment-friendly and the cost of operation and maintenance is also very low. The researchers have identified that the parameters which have a certain influence over the performance mechanics of the screw turbine are shaft slope, pitch distance and water discharge [23]. In a research performed by the researchers the effect that discharge variation and shaft slope will have on the performance mechanics of a two-blade screw turbine was calculated. The experiment will be performed at the laboratory scale where two-blade screw turbines were used [24]. The pitch of the screw was 1.6,External radius, R_o = 0.1419 m, Internal radius, R_i = 0.0762 m. The average discharge of water for the experiment was between 0.00364 m^3/s to 0.00684 m^3/s, whereas the angle that was considered for the turbine shaft was between 25^o to 50^o. From the results of the experiment, it was clear that both turbine shaft slope and discharge have a direct effect on the power and efficiency of the turbine. The highest efficiency and power that was produced at an average discharge was recorded at 0.00684m^3/s.

Lyons & Lubitz [17] have analyzed the popularity of the Archimedes screw turbines and its usage. These turbines are highly preferred at hydro sites in Europe. The reason for their popularity is mainly due to the high efficiency delivered, low cost of installation and maintenance and very low impact on the environment. It has been observed that the greatest potential of Archimedes screw turbine can be achieved at low head sites [25]. Various parameters of Archimedes screw turbine such as the inner and outer diameter of the screw, pitch of the screw, inlet and outlet conditions, slope, head and flow of water are responsible for the performance of the turbine. These parameters are also useful in calculating RPM, Torque, Power and efficiency of the Archimedes screw turbine. For the validation and support of the findings, laboratory tests were performed on the Archimedes screw turbine [26]. Through the study, the researchers have examined the relationship that exists between the power, torque and rotation speed [27]. The results of the tests showed that the efficiency on average was maintained by the Archimedes screw turbine over different operating conditions. There were some instances where efficiency was recorded to be high. The main reason for varying output power was identified as the varying water levels at the outlet [28]. This was because of the variation in the head; dynamic limiting of the screw rotation speed will also have a significant effect over the flow of water through the screw. As it is seen that there is a huge amount of problems being faced by generating energy by tradiational ways it is very important for researchers to find out different ways to generate energy.

Table 1. Summary of work in the field of Archimedes Screw Turbine

<table>
<tr><th>Author/ Ref</th><th>Experimental Setup</th><th>Parameters</th><th>Findings</th></tr>
<tr><td>Michal Lisicki. et al.(2016) [29]</td><td>
</td><td>Single bladed AST with head 1 to 6 m and tilt angle $\mathbf{18^o}$ to $\mathbf{36^o}$ with flow rate 0 to 1.5 liters/second</td><td>Maximum efficiency came at angle $\mathbf{18^o}$ and at 1.5 litres/second</td></tr>
<tr><td>Erinofiardia. et al. (2017) [15]</td><td>
</td><td>Single bladed AST with tilt angle $\mathbf{22^o}$ to $\mathbf{40^o}$ with flow rate 1.2 litres/second</td><td>Maximum efficiency at $\mathbf{22^o}$ medium for $\mathbf{30^o}$ and minimum at $\mathbf{40^o}$ respectively.</td></tr>
<tr><td>Zafirah Rosly. et al. (2016) [30]</td><td>
</td><td>Two and three bladed AST with tilt angle $\mathbf{35^o}$</td><td>Highest efficiency of 81 % is attained with 2 blades and 3 helix turns.</td></tr>
<tr><td>Julien Rohmer. et al. (2016)

[31]</td><td>
</td><td>Three bladed AST with tilt angle $\mathbf{30^o}$ head 1 to 6.5 m and discharge 0.15 $\boldsymbol{m^3/s}$</td><td>The overall efficiency was 72%</td></tr>
</table>

Lee, Kim et al. (2015) [32]		Four bladed AST with tilt angle $\mathbf{45^o}$and flow rate 0.04$\boldsymbol{m^3/s}$	Evaluated efficiency was 71%
Saroinsong, Soenoko et al. (2016) [33]		Three bladed AST with tilt angle $\mathbf{25^o}$,$\mathbf{35^o}$and $\mathbf{45^o}$ with velocity 0.3,0.4 and 0.5 $\boldsymbol{m/s}$	Maximum efficiency 89% evaluated at 25° and Inflow velocity 0.5 m/s
Shimomura and Takano (2013) [34]		Four bladed AST with tilt angle $\mathbf{20^o}$ and flow rate 10.5 litres/second	Geometry of turbine and rotation rate are closely related to each other
Müller and Senior (2010)[35]	 (a)	AST with 14 number of turns head 2.35 m, tilt angle $\mathbf{26^o}$and flow rate 60 litres /second	The research paper concluded that with the increase in head, efficiency decreases
E. Fiardi (2014) [36]		Single bladed AST at tilt angle $\mathbf{45^o}$and discharge 0.00019 $\boldsymbol{m^3/s}$	Maximum efficiency 41% came with output power of 0.0098W
Juliana Putu et al. (2018) [37]		Single bladed AST with 150 cm turbine housing, Turbine housing dia 27cm at tilt angle $\mathbf{0^o}$ to 9$\mathbf{0^o}$	Maximum speed 303 RPM was recorded at $\mathbf{40^o}$. Maximum output power 10.92 watts, torque 0.60Nm and 14% efficiency was recorded.
I Kadek et al. (2019) [38]		Single blade with distance 10 ,12 and 15 cm and pitch 18 ,22 and 25 cm	Efficiency 24.5% was recorded at pitch 22 cm and slope $\mathbf{28^o}$

3. Methodology

Various researchers have considered the Archimedes Screw turbine as a potential candidate for the efficient generation of electricity at low head sites and each researcher has taken a different approach in determining various effects of each parameter on the power output as well as on the efficiency of the complete [39]. Thus, the traditional water mills of the Western Himalayan Region which are also known as Gharats can be renovated and fitted with the Archimedes Screw turbine as these gharats work on a low head and low flow rate conditions [40] [41],This is also very important to get the feasibility of other turbines than the traditional ones because of the silt problem faced in rivers especially in rainy season [42][43][44]. For the research it was very important to get the actual parameters at different locations of water mills and further do the experimentation on those parameters and get the optimum results. For this the study undergone in two different stages as discussed below.

3.1. Getting actual parameters

For gathering the actual parameters, we undergone a survey at 76 different locations of water mills and the readings were taken for flow rate, angle of inclination, head and discharge. These readings were collected and further after analysing the data range of parameters were finalized as shown in table 2.

Table 2. Range of parameters

Sr. No	Parameter	Range
1	Discharge	0.00099 -0.00385 m^3/s
2	Flow rate	1-4 l/s
3	Head	1-6 m
4	Angle of Inclination	20-50°
5	Length of Penstock	1-5 m

3.2 Experimentation

Based on the actual parameters an improvised experimental setup was designed and fabricated to get the results essential to find the efficiency factor respectively the diagrammatic view and 3D view of the experimental setup is shown in Fig 2.

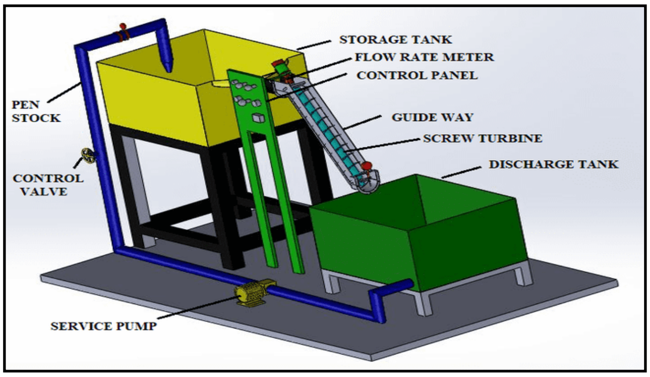


Fig.1 3D view of the setup

The setup consists of inlet water controller, Archimedes Screw, Load-Brake System, Screw Angle Controller, Inlet tank, Discharge Tank.

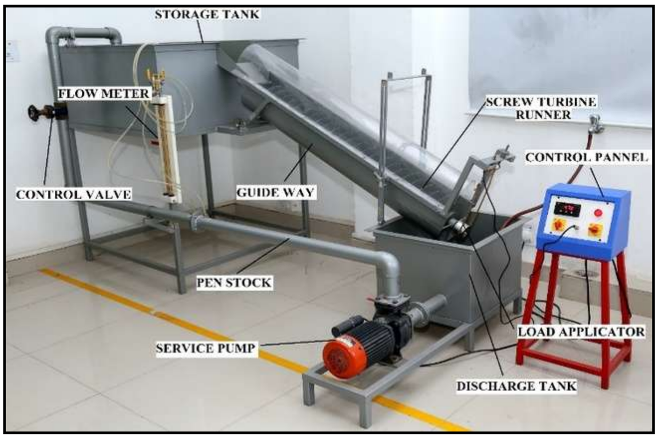


Fig.2 Pictorial view of the setup

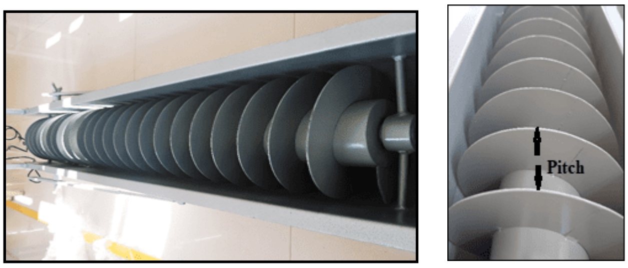
Table 3. Parameters undertaken for setup

Parameter	Symbol	Dimensions/Range
Length of screw	L_{screw}	1.626m
Rope Diameter	Dia_{rope}	0.0064m
Brake Diameter	Br_{dia}	0.1m
Density of water	ρ_{wa}	997kg/m^3
Pitch	P_{itch}	0.1m,0.2m,0.3m
Inner Diameter Turbine	Dia_{inner}	0.0762m
Outer Diameter Turbine	Dia_{out}	0.198m
Flow Rate	F_{rate}	(1,1.5,2,2.5,3,3.5,4) litres
Screw tilt Angle	Sc_{angle}	(20,25,30,35,40,45,50) degrees
Head	H_{ead}	0.56,0.69,0.81,0.93,1.05,1.15,1.25m
Load	L_{oad}	(0.5,0.7,0.9) Kg

To find the efficiency of turbine the parameters are given in the Table 3 which are essential to get the overall efficiency, Power input, Power Output etc. The description of all the equipment's of which the apparatus consist of are given as below.

3.2.1 Archimedes screw turbine

Three different screw turbines were used varying the pitch as shown in the Fig.3 (a) and (b) and the screw turbine was made from stainless steel and was coated with paint to decrease frictional losses and to decrease rusting. The parameters of the screw turbine are shown in the Table 4.



(a) (b)

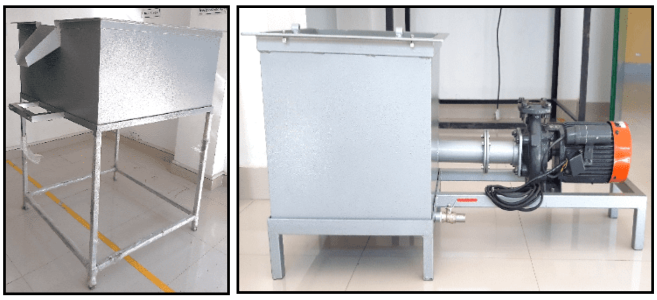
Fig.3 (a) Side view of Archimedes screw turbine (b) Top view of archimedes screw turbine

Table 4. Range of parameters of Archimedes screw turbine (Runner)

Sr.NO	Parameter	Runner 1	Runner 2	Runner 3
1	L_{screw}(m)	1.626	1.626	1.626
2	Dia_{inner}(m)	0.08	0.08	0.08
3	Dia_{out} (m)	0.2	0.2	0.2
4	P_{itch}(m)	0.1	0.2	0.3
5	$P_{\mathrm{itch}}/Dia_{\mathrm{out}}$	0.5	1	1.5

3.2.2 Water tanks

Two separate water tanks one for storage and another for outlet tank was used. The first water tank was very essential to give water supply to the turbine and another tank was used to give continuous flow of water. The discharge measuring tank was additionally given in the output tank to measure discharge of water. The images of the tanks are given in Fig.4.



(a) (b)

Fig. 4 (a) Storage tank (b) Outlet water tank

3.2.3 Service pump and penstock pipe

Service pump of pumping capacity of 5 liters/second was used to supply regular water to the storage tank and penstock pipe diameter 0.052m was used for the proper supply of water as shown in Fig.5 and Fig.6

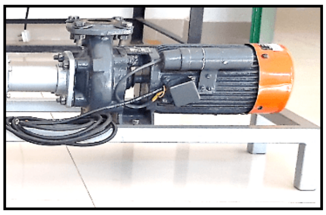


Fig.5 Service pump

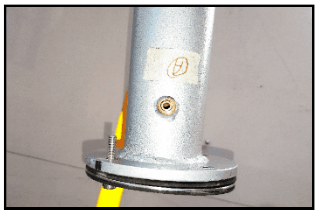


Fig.6 Penstock pipe

3.2.4 Rope brake drum dynamometer with load controlling unit

To measure the load a rope brake drum of 0.1m diameter and rope of diameter 0.0064m was introduced in the setup. Load applicator screw with digital load measuring unit was included as shown inf Fig.7. To increase and decrease the screw angle a screw angle controller with screw angle measurer was also included in the apparatus as shown in Fig.8.

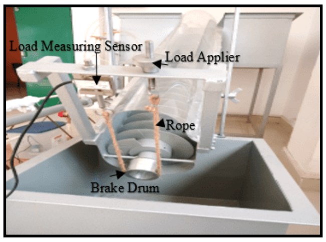


Fig.7 Brake drum with load controlling unit

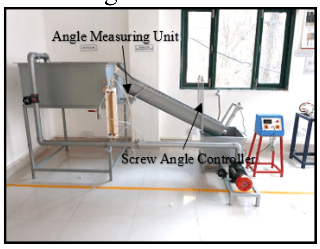


Fig.8 Angle controller and measuring unit

3.2.5 Manometer and orifice plate

To measure the flow rate manometer was used along with orifice plate the orifice plate was having diameter ($D_{orifice}$=0.026m) and the diameter of pipe was (D_{pipe}= 0.052m), mercury was used as a measuring agent to measure h_1 and h_2 .

Flow rate was measured by formula

F_{rate}=

$$C_{discharge} \cdot (A_{orifice} \times A_{pipe} \times \sqrt{2.g.H_{ead}} / \sqrt{A_{pipe^2} - A_{orifice^2}}) \quad \textbf{(1)}$$

$C_{discharge}$= 0.64

g = 9.81

$$A_{orifice} = \frac{\pi}{4} D_{orifice^2} \quad \textbf{(2)}$$

$$A_{pipe} = \frac{\pi}{4} D_{pipe^2} \quad \textbf{(3)}$$

$$H_{ead} = (h_1 - h_2)/100 \times (13600/1000 - 1) \quad \textbf{(4)}$$

where

F_{rate} = Flow rate

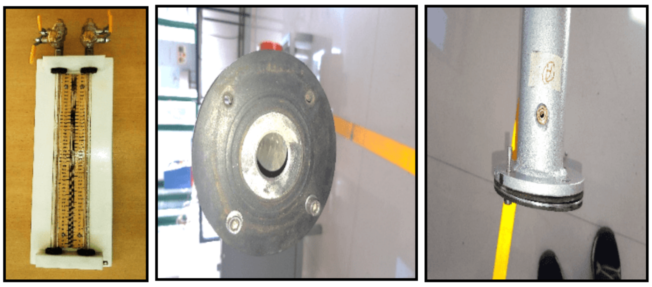
$C_{discharge}$ = Coefficient of discharge

$A_{orifice}$ = Orifice plate area

A_{pipe} = Pipe area

$D_{orifice}$= Diameter of orifice plate

D_{pipe}= Diameter of pipe.



(a) (b) (c)

Fig.9 (a) Manometer (b) Orifice plate (c) Water connecting medium to manometer

3.6 Control panel and tachometer

To control and to measure the quantities control panel was used. The control panel consist of a digital display to display load an on/off switch. A digital tachometer was used to measure the revolution per minute of the turbine.

4 Experımental procedure

Experimentation was undertaken by doing the following procedures:

1. In the first step service pump draw water from the tank and water was supplied to the turbine. The turbine was connected on both ends by ball bearing. The flow of water was be controlled with the help of control valve. The flow at the inlet was measured with the help of a flow meter and was kept constant for every experiment. Water from the turbine then flow to the discharge tank. In the discharge tank a separate tank was provided to measure the discharge of water.
2. Secondly, a load applying mechanism was provided at the one end of the turbine and load was kept constant throughout the experimentation. At same load the readings of RPM with the help of a digital tachometer at different angle of inclination was measured.
3. In the third step, the reading was taken on all three turbines by keeping one parameter as variable and others as fixed, one set of readings was taken for four values of considered parameter, at a time interval of two hours.

5 Calculatıons

The overall efficiency of the turbine is calculated as below

$\eta = (Powr_{out}/Powr_{in}) \times 10$ **(5)**

The available power is the hydraulic power that can be produced through the Archimedes screw setup as per the discharge rate and head conditions while ignoring all the losses:

$Powr_{in} = \rho_w \times g \times He_{ad} \times Q_d\ (Kw)$ **(6)**

Where

$\rho_w = 997\ kg/m^3$

$g = 9.81 m/s^2$

The output power is calculated as

$Powr_{out} = 2 \times \pi \times n_r \times t_{orq}/60 \times 1000\ (Kw)$ **(7)**

Where

$\pi = 3.14$

To calculate the Torque (t_{orq}), the following formula is applicable

$t_{orq} = L_{oad} \times g \times Re_{adius}$ **(8)**

Where

$g = 9.81 m/s^2$

The torque produced on the screw due to the rotation of the screw can be measured by applying a load across the screw and then can be measured. The load is applied through a rope and brake system to calculate the torque for each load specification. To calculate the torque, the equivalent radius is required which is calculated as:

$R_e = (Br_{dia} + 2Dia_{rope})/2 \quad (m)$ **(9)**

6 Results and analysıs:

The setup was run for two hours recording various values under various parameters determine their relations with various parameters. The following are the findings of the experiment

6.1 Effect of various parameters on efficiency (η)

The variation of Efficiency (η) v/s Flow rate (F_{rate}) and Load (L_{oad}) is shown in Fig: 10 which shows that with the increase of flowrate screw turbine tends to decrease the efficiency. It shows that Archimedes screw turbine works most efficiently at low flow rates. Also, it was noted that at load 0.9 Kg and Minimum Flow Rate of (1 L/s), the efficiency was recorded to be maximum at a value of 70.02% at 68 rpm.Change in the flowrate and load affects the efficiency of the system, efficiency increase with the increase in load.

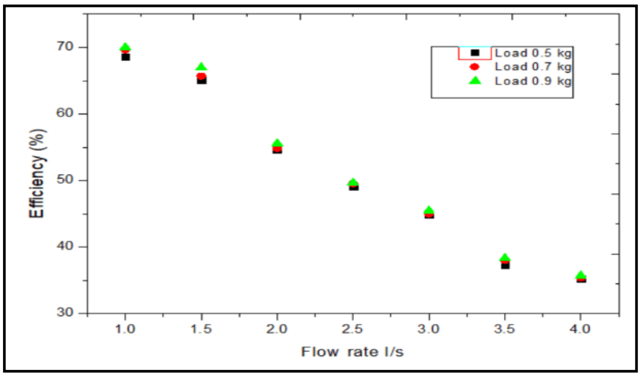


Fig.10 Efficiency (η) v/s Flow rate (F_{rate}) and Load (L_{oad})

In Fig11: Efficiency (η) v/s Tilt angle (Sc_{angle}) and Flow Rate (F_{rate}) was illustrated which shows with change in the tilt angle changes the overall efficiency for the Archimedes Screw Turbine

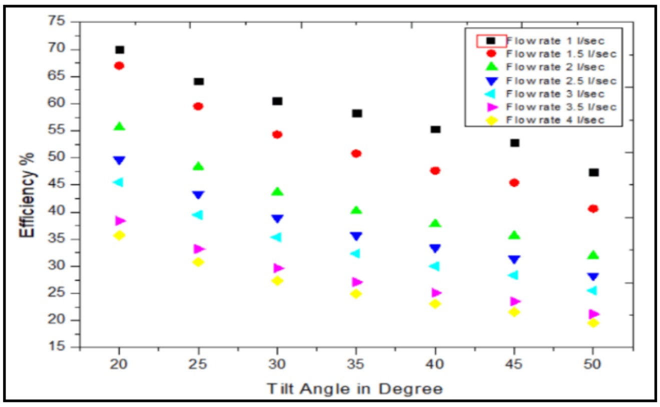


Fig.11 Efficiency (η) v/s Tilt angle (Sc_{angle}) and Flow Rate (F_{rate})

It is analyzed that as tilt angle increase, the overall efficiency decreases for the screw turbine which further decreases with the increase in the flow rate friction as well as overflow from each bucket of the screw which leads to decrease in the efficiency.

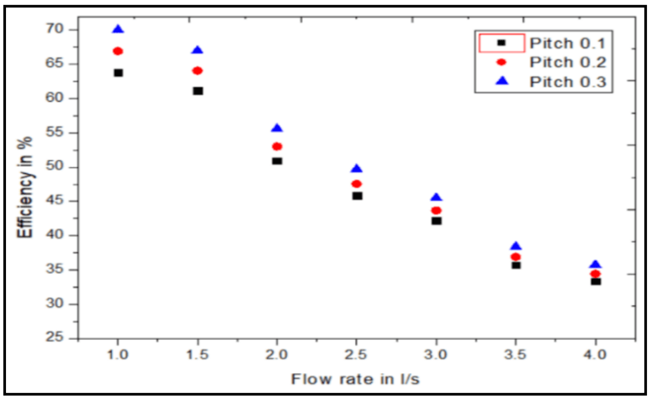


Fig.12 Efficiency (η) v/s Flow Rate (F_{rate}) at Variable Pitch (P_{itch})

Fig.12 illustrates the effect on Efficiency (η) V/S Flow Rate (F_{rate}) at Variable Pitch (P_{itch}) it shows that pitch is also an important factor in Archimedes screw turbine it has been observed by experimentation that with the increase in pitch the overall efficiency of the turbine increases. Maximum efficiency 70.01 % comes at pitch 0.3 m ,66.92 % at pitch 0.2 m and 63.83% at pitch 0.1m.

6.2 Effect of various parameters on input power ($\boldsymbol{Power_{in}}$)

Input as it depends upon discharge (Q), Head (H_{ead}), gravitational constant (g) and water density $998kg/m^3$ increase with the rate of flow and head. Maximum input power of 0.047 kw noted at head value 1.25 m and flow rate 4 l/s as shown in Fig.13

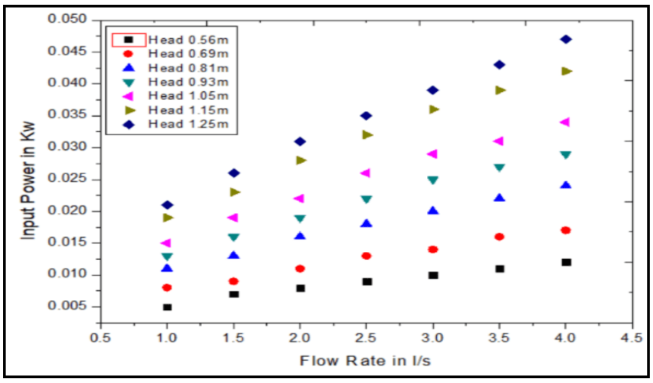


Fig.13 Input power (P_{itch}) v/s Flow rate (F_{rate}) and Variable head (H_{ead})

6.3 Effect of various parameters on output power ($\boldsymbol{Power_{out}}$)

Output power ($Powr_{out}$) v/s Tilt angle (Sc_{angle}) at variable Flow rate (F_{rate}) is illustrated in Fig.14. Maximum output power 0.00915 kw during experimentation comes at flow rate $4l/s$ at tilt angle 45^o load 0.9 kg and pitch 0.3.

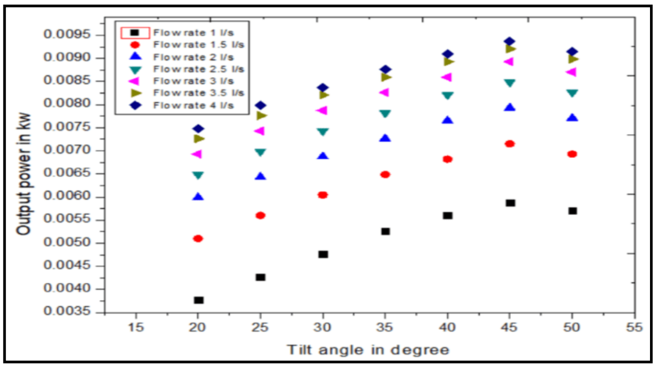


Fig.14 Output power ($Powr_{out}$) v/s Tilt angle (Sc_{angle}) at variable Flow rate (F_{rate})

It was also being observed during experimentation that output power increases up to the tilt angle of turbine reaches 45^o and then afterwards start to decline with the increase in tilt angle.

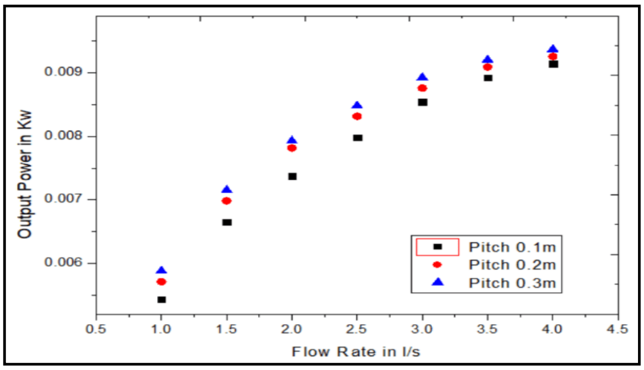


Fig.15 Output Power ($Powr_{out}$) v/s Flow rate (F_{rate}) at variable Pitch (Pi_{tch})

Further the effect of Flow rate (F_{rate})at variable Pitch (Pi_{tch}) is shown in Fig .15 which indicates that output power of the

Archimedes screw turbine is directly proportional to the Flowrate and Pitch. Thus, with the increase in pitch increases the output power wrt flow rate. Maximum output power.Output Power ($Powr_{out}$) is also dependable on Flowrate (F_{rate}) and Load (L_{oad}) which is shown in Fig.16 load was varied from 0.5 kg to 0.9 kg and he maximum values of load comes at 0.9 kg.it shows that with the increase in load increases the output power of the turbine.

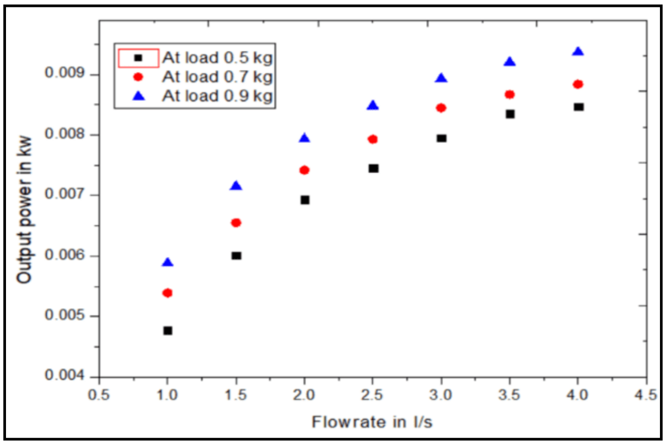


Fig. 16 Output Power ($Powr_{out}$) v/s Flowrate (F_{rate}) at variable Load (L_{oad})

6.4 Effect of various parameters on RPM (Revolution per minute)

RPM (Revolution Per Minute) is directly dependent upon Tilt angle *(Sc_{angle})* and Flow rate *(F_{rate})* as shown in Fig.17

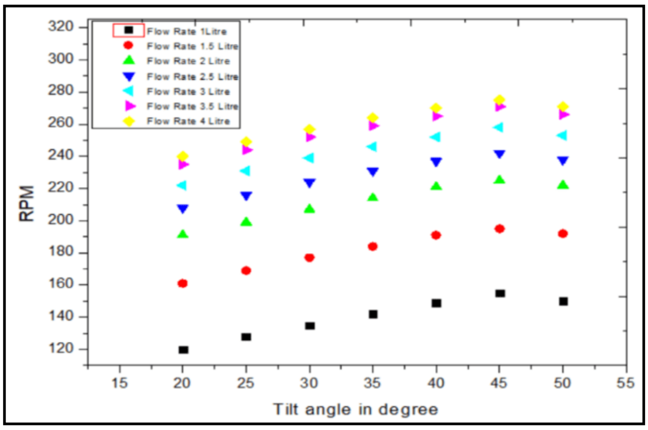


Fig. 17 RPM (Revolution Per Minute) v/s Tilt angle *(Sc_{angle})* at variable Flow rate *(F_{rate})*

RPM (Revolution per minute) of the turbine varies form 62 rpm at flow rate 1 l/s at load 0.9kg and pitch 0.1m at $20^{o}$to 275 rpm at 45^{o} with load 0.5 kg and pitch 0.3 metre. It was observed that like output power RPM also starts to decline after 45^{o} onwards due to the increase in losses

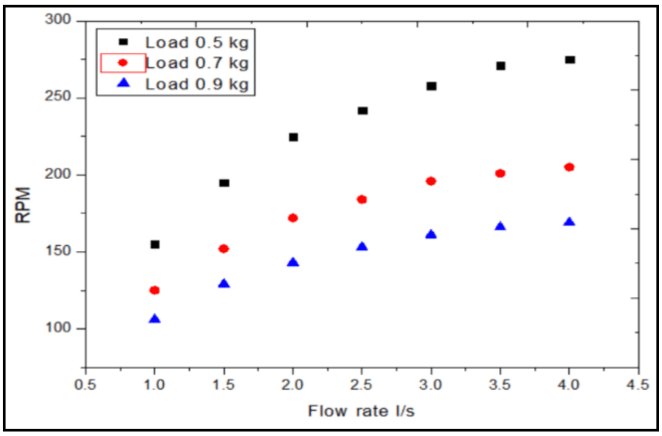


Fig. 18 RPM (Revolution Per Minute) v/s Flow rate (F_{rate}) at variable Load (L_{oad})

.Further in Fig.18 the effect of Flow rate *(F_{rate})* and Load (L_{oad}) on RPM is indicated which shows with the increase in load RPM decreases. At load 0.9 kg minimum and at load 0.5kg maximum RPM was attained at flow rate 4l/s.

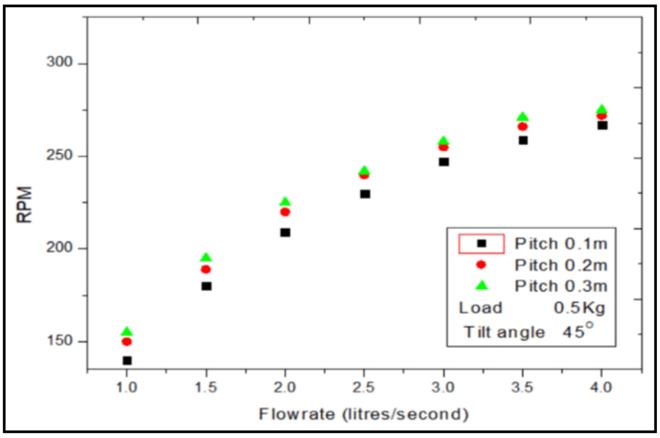


Fig 19 RPM (Revolution Per Minute) v/s Flow rate *(F_{rate})* at variable Pitch (P_{itch})

The variation is seen from 155 to 275 rpm at 0.5kg, 125 to 205 at 0.7 kg and 106 to 169 at 0.9 kg.Fig.19 shows that with the increase in pitch RPM increases because the area between the blades increase due to increment in pitch so the bucket fill increases which in return increase the RPM.On pitch 0.1m it ranges from 104 rpm to 267 rpm at variable flow rate, 150 rpm to 252 rpm by varying flow rate and maximum 155 rpm to 275 rpm at pitch 0.3 m considering other parameters constant load 0.5 kg and tilt angle 45^{o}.

6.5 Experimental validation

Validation has been done for the experimental setup by considering theoretical efficiency as mentioned in equation 10. The deviation between the values of experimental results and from theoretical calculations is found to be with in ±3% as shown in Fig.20.

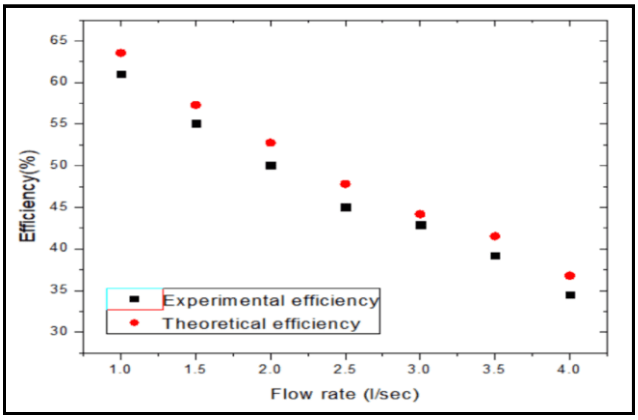


Fig .20 Result validation by comparing theoretical and experimental efficiency

The theoretical efficiency was determined by using the equation

$$\eta = 2n + 1/2n + 2 \quad \textbf{(10)}$$

where

η= theoretical efficiency of screw turbine.

$$n = do/\Delta d \quad \textbf{(11)}$$

$$do = \text{Water entry depth}$$

$$\Delta d = \frac{L}{m}\, tan\alpha \quad \textbf{(12)}$$

Where

$L = Length\ of\ screw$

$m = Turn\ of\ the\ helix$

$\alpha = Screw\ tilt\ angle$

6.6 Uncertainty Analysis

Table 5 shown below shows the uncertainty related to instruments used in this current experimentation.

Table 5. Uncertainty Analysis of Archimedes screw turbine system

Sr No.	Measurement	Instrument	Uncertainty
1	Revolution Per Minute	Tachometer	± 1 rpm
2	Dimensions	Digital Vernier Caliper	± 0.1 mm
3	Load	Digital Load Meter	±0.01 kg
4	Length	Measuring Tape	± 1 mm at the edge
5	Head	U tube Manometer	± 1 mm

The electrical efficiency of the system can be calculated by the following equation:

$$\eta = Output\ power\ /\ Input\ energy\ * 100$$

$$\eta = \frac{2\times\pi\times n_r \times to_{rq}}{60} \cdot \frac{1000}{\rho_w \times g \times He_{ad} \times Q_d} \times 100$$

$$\frac{\delta\eta}{\eta} = \sqrt{\left(\frac{\partial n_r}{n_r}\right)^2 + \left(\frac{\delta To_{rq}}{To_{rq}}\right)^2 + \left(\frac{\delta He_{ad}}{He_{ad}}\right)^2 + \left(\frac{\delta Q_d}{Q_d}\right)^2} \text{ ....(13)}$$

Uncertainty in RPM (n_r)

$$\frac{\delta nr}{nr} = \sqrt{\left(\frac{\partial nr}{nr}\right)^2}$$

$$\sqrt{\left(\frac{1}{108}\right)^2} = 0.00926 \text{..................................}\textbf{(14)}$$

6.6.1 Uncertainty in Torque (To_{rq})

$To_{rq} = Lo_{ad} \times g \times Re_{adius}$

$$\frac{\delta Torq}{Torq} = \sqrt{\left(\frac{\partial Lo_{ad}}{Lo_{ad}}\right)^2 + \left(\frac{\delta Re_{adius}}{Re_{adius}}\right)^2} \text{ ....}\textbf{(15)}$$

6.6.2 Uncertainty in Load (Lo_{ad})

$$\frac{\delta Lo_{ad}}{Lo_{ad}} = \sqrt{\left(\frac{\delta Lo_{ad}}{Lo_{ad}}\right)^2}$$

$$= \sqrt{\left(\frac{0.01}{0.9}\right)^2} = 0.0111 \text{..................................}\textbf{(16)}$$

Uncertainty in Equivalent Radius (Re_{adius})

$$\frac{\delta Re_{adius}}{Re_{adius}} = \sqrt{\left(\frac{\partial Br_{dia}}{Br_{dia}}\right)^2 + \left(\frac{\delta Dia_{rope}}{Dia_{rope}}\right)^2}$$

$$= \sqrt{\left(\frac{0.0001}{0.1}\right)^2 + \left(\frac{0.0001}{0.0064}\right)^2}$$

$$= \sqrt{.000001 + 0.0002441}$$

$$= \sqrt{.0002451} = 0.01565 \text{............}\textbf{(17)}$$

6.6.3 Uncertainty in Torque (To_{rq})

$$\frac{\delta Torq}{Torq} = \sqrt{\left(\frac{\partial Lo_{ad}}{Lo_{ad}}\right)^2 + \left(\frac{\delta Re_{adius}}{Re_{aduis}}\right)^2}$$

$$= \sqrt{.0001232 + 0.00024492}$$

$$= \sqrt{.00036812} = 0.019186 \text{........................}\textbf{(18)}$$

6.6.4 Uncertainty in Discharge (Q_d)

$Q_d = Fr_{ate}$ *per unit time*

$$\frac{\delta Qd}{Qd} = \sqrt{\left(\frac{\partial Fr_{ate}}{Fr_{ate}}\right)^2 + \left(\frac{\delta T}{T}\right)^2} \quad \text{...............................} \mathbf{(19)}$$

6.6.5 Uncertainty in Time(T)

$$\frac{\delta T}{T} = \frac{0.01}{10} = 0.001 \quad \text{.......................................} \mathbf{(20)}$$

Uncertainty in Flow rate (Fr_{ate})

$$\frac{\delta Fr_{ate}}{Fr_{ate}} = \sqrt{\left(\frac{\partial \mathrm{Do}_{rifice}}{\mathrm{Do}_{rifice}}\right)^2 + \left(\frac{\partial \mathrm{Dp}_{ipe}}{\mathrm{Dp}_{ipe}}\right)^2 + \left(\frac{\partial \mathrm{He}_a}{\mathrm{He}_a}\right)^2}$$

$$= \sqrt{\left(\frac{0.0001}{0.0260}\right)^2 + \left(\frac{0.0001}{0.0520}\right)^2 + \left(\frac{0.1}{8.75}\right)^2}$$

$$= \sqrt{0.0001476 + 0.0000369 + 0.0001305}$$

$$= \sqrt{0.00014896} = 0.0122049 \quad \text{....................................} \mathbf{(21)}$$

By putting (20) and (21) in (19)

$$\frac{\delta Qd}{Qd} = \sqrt{0.0122049^2 + 0.001^2}$$

$$= \sqrt{0.0001486 + 0.00001}$$

$$= \sqrt{0.000149} = 0.012245 \quad \text{...................................} \mathbf{(22)}$$

6.6.6 Uncertainty in Head (He_{ad})

$$\frac{\delta He_{ad}}{He_{ad}} = \sqrt{\left(\frac{\partial Ls_{crew}}{Ls_{crew}}\right)^2 + \left(\frac{\partial Sc_{angle}}{Sc_{angle}}\right)^2} = \sqrt{\left(\frac{0.0001}{1.626}\right)^2 + \left(\frac{0.05}{20.0}\right)^2}$$

$$= \sqrt{0.000000378 + 0.00000625}$$

$$= \sqrt{0.0000066282} = 0.008141 \quad \text{................................} \mathbf{(23)}$$

By putting the values of eqn. (14), (18), (22) and (23) in eqn. (13) we get,

$$\frac{\delta\eta}{\eta} = \sqrt{(0.00926)^2 + (0.0191)^2 + (0.012245)^2 + (0.008141)^2}$$

$$= \sqrt{0.00008574 + 0.00036481 + 0.00014994 + 0.00006625}$$

$$= \sqrt{0.00066676}$$

$$= 0.02582$$

Hence, maximum relative error in Electrical Efficiency is 2.582%.

7 Conclusıons

Archimedes screw turbine has lot of potential to be used as a hydro power source in the Himalayan region where still many people living their lives in darkness in rainy and winter seasons. Current research represents the utilization scope of Archimedes screw turbine at water mills location for electrification in rural areas. Firstly, undergone a survey to identify the places of water mills being utilised to install the turbine and the actual flow condition reading for head, flowrate etc were taken. After that the experimentation was done under laboratory conditions.

The study undergoes in two stages and the following conclusions were drawn:

- It has been identified that over 70% of the water mill locations are showing favourable conditions for Archimedes screw turbine to be installed.
- Maximum efficiency of 70% has been observed at screw tilt angle of 20°, flow rate of 1L/s, pitch 0.3 m at the speed of 68 rpm with load 0.9kg.
- It is further observed that with the increase in pitch the output power and efficiency increase because output power is directly proportional to the tilt angle of screw runner, head, pitch as well as load on runner.
- Maximum output power of 0.009149 KW has been found at the tilt angle of 45° , pitch 0.3m with a load of 0.9 kg as well as maximum speed of 275 rpm has been found at load of 0.5 kg, pitch 0.3m and tilt angle 45° .
- The obtained results show the compatibility of turbine being utilised for electricity generation in distant places which in return will enhance the living standards of the people and will open up new opportunities for development in these places.

References

1. A. I. Siswantara, Warjito, Budiarso, R. Harmadi, M. H. Gumelar S, and D. Adanta, "Investigation of the α angle's effect on the performance of an Archimedes turbine," Energy Procedia, vol. 156, pp. 458-462, 2019.
2. R. Naveen, P.P.R., S. Rajanna, Integration of Renewable Energy Systems for Optimal Energy Needs-a review. International Journal of Renewable Energy Research. Vol. 10(2): pp. 728-742, 2020.
3. M. Beken, B. Hangun, and O. Eyecioglu, "Classification of Turkey among European Countries by Years in Terms of Energy Efficiency, Total Renewable Energy, Energy Consumption, Greenhouse Gas Emission and Energy Import

Dependency by Using Machine Learning,"8th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 951-956, 2019.

4. S. Naseem, M. I. A. , Muhammad Kamran, M. R. F. , G. Abbas, and M. R. A. , Zunair Zamir, "Rural Areas Interoperability Framework: Intelligent Assessment of Renewable Energy Security Issues in PAKISTAN," International Journal Of Smart Grid, vol. 4, no. 2, 2020.

5. N. Campagna, M. Caruso, V. Castiglia, R. Miceli, and F. Viola, "Energy Management Concepts for the Evolution of Smart Grids," 8th International Conference on Smart Grid (icSmartGrid), pp. 208-213, 2020.

6. C. I, B. R, and S. S, "The Effects of the Smart Grid System on the National Grids," 8th International Conference on Smart Grid (icSmartGrid), pp. 122-126, 2020.

7. M. Shimomura and M. Takano, "Modeling and Performance Analysis of Archimedes Screw Hydro Turbine Using Moving Particle Semi-Implicit Method," Journal of Computational Science and Technology, vol. 7, no. 2, pp. 338-353, 2013.

8. K. Shimokawa, A. Furukawa, K. Okuma, D. Matsushita and S. Watanabe, “Experimental study on simplification of Darrieus-type hydro turbine with inlet nozzle for extra-low head hydropower utilization” Renewable Energy, vol.41, pp. 376-382, 2013.

9. N. Kishor, R. Saini & S. Singh, “Small hydro power plant identification using NNARX structure” Neural Computing and Applications, vol.14, no.3, pp.212-222, 2005.

10. M. Jager, M. Schwarz, D. Auer, B. Platzer and J. Kung, “Connecting small, private & independent hydro power plants to increase the overall power generating efficiency” Procedia Computer Science, vol.109, pp. 841-848, 2017.

11. H. Kouno, R. Isohata, S. Era and D. Matsushita “Study on Performance and Installation of Portable type Darrieus Hydro Turbine in Extra Low Hydropower” Conference of Kyushu Branch, No. 71, 2018.

12. E. M. Malatji, "The use of Dynamic Tariff by The Utilities to Counter act The Influence of Renewable Energy Sources," 7th International Conference on Smart Grid (icSmartGrid), pp. 103-107, 2019.

13. U. Nerlich. “Towards Europe 2035 - In Search of the Archimedean Screw FOCUS” Perspective Information & Security: An International Journal, vol. 29, pp. 161-183, 2013.

14. P. Sritram and R. Suntivarakorn, “Comparative Study of Small Hydropower Turbine Efficiency at Low Head Water”, Energy Procedia, vol. 138, pp. 646-650, 2017.

15. Erinofiardi, A. Nuramal ,P. Bismantolo, A. Date, A. Akbarzadeh, A. Mainil and A. Suryono, “ Experimental Study of Screw Turbine Performance based on Different Angle of Inclination” Energy Procedia, vol. 110, pp. 8-13, 2017.

16. H. Dedic-Jandrek and S. Nizetic, “Small scale archimedes hydro power plant test station: Design and experimental investigation”, Journal of Cleaner Production, vol.231, pp. 756-771, 2019.

17. W. Lubitz, M. Lyons and S. Simmons, “Performance model of Archimedes screw hydro turbines with variable fill level”, Journal of Hydraulic Engineering, vol. 140, no. 10, 2014.

18. J. Rohmer, D. Knittel, G. Sturtzer, D. Flieller and J. Renaud, “Modeling and experimental results of an Archimedes screw turbine”, Renewable Energy, vol. 94, pp. 136-146, 2016.

19. B. Yulistiyanto and Y. Hizhar, “Effect of flow discharge and shaft slope of Archimedes (screw) turbine on the micro-hydro power plant”, Dinamika teknik sipil, vol. 12, no. 1, 2012.

20. V. Kulkarni and K. Kulkarni, "A Blockchain-based smart grid model for rural electrification in India," 8th International Conference on Smart Grid (icSmartGrid), pp. 133-139, 2020.

21. D. Matsushita, K. Okuma, S. Watanabe and A. Furukawa, “Simplified structure of ducted darrieus-type hydro turbine with narrow intake for extra-low head hydropower utilization”, Journal of Fluid Science and Technology, vol. 3, no.3, pp. 387-397, 2008.

22. R. Caldon and F. Pasut, “Innovative Control Strategy for Islanded Small Hydro Power Plant”, Journal of Energy and Power Engineering, vol. 8, no.1, 2014.

23. A. Date and A. Akbarzadeh, “Design and cost analysis of low head simple reaction hydro turbine for remote area power supply”, *Renewable Energy*, vol. *34*, no. 2, pp. 409-415, 2009.

24. M. Maulana, Darwin and G. Putra, “Performance of single screw Archimedes turbine using transmission”, IOP Conference Series: Materials Science and Engineering, pp. 536-545, 2019.

25. V. Berlin and O. Murav’ev, “Governing the turbine-generator unit of a small-scale hydropower plant with a long penstock”, Power Technology and Engineering, vol. 49, no.4, pp. 240-244, 2015.

26. J. Monserrat, “Energy saving in a variable-inclination Archimedes screw”, Irrigation & Drainage Systems Engineering, vol. 04, no. 1, 2015.

27. C. Becker Tische,J. Tibola,L. Giuliani Scherer and R. Camargo, “Proportional-Resonant control applied on voltage regulation of standalone SEIG for micro-hydro power generation”, IET Renewable Power Generation.doi: 10.1049/iet-rpg.2016.0857, 2017.

28. M. Mutasim, N. Azahari and A. Adam, “Prediction of Particle Impact on an Archimedes Screw

Runner Blade for Micro Hydro Turbine," Applied mechanics and materials, Vol. 53 pp. 552-556, 2013.

29. M. Lisicki, W. Lubitz, and G. W. Taylor, "Optimal design and operation of Archimedes screw turbines using Bayesian optimization," Applied Energy, vol. 183, pp. 1404-1417, 2016.

30. U. K. J. C. Zafirah Rosly, N. Suraya Azahari, M. Ammar Nik Mu'tasim,A. Nurye Oumer and N. T. Rao, "Parametric study on efficiency of archimedes screw turbine," ARPN journal of engineering and applied sciences, vol. 11, no. 18, pp. 10904-10908, 2016.

31. J. Rohmer, D. Knittel, G. Sturtzer, D. Flieller, and J. Renaud, "Modeling and experimental results of an Archimedes screw turbine," Renewable Energy, vol. 94, pp. 136-146, 2016.

32. K. T. Lee, E.S. Kim, W.S. Chu, and S.H. Ahn, "Design and 3D printing of controllable-pitch archimedean screw for pico-hydropower generation," Journal of Mechanical Science and Technology, vol. 29, no. 11, pp. 4851-4857, 2015.

33. T. Saroinsong, R. Soenoko, S. Wahyudi, and M. N. Sasongko, "Fluid flow phenomenon i n a three - bladed power - generating Archimedes screw turbine," Journal of Engineering Science and Technology Review, vol. 9, no. 2, pp. 72-77, 2016.

34. M. Shimomura and M. Takano, "Modeling and Performance Analysis of archimedes screw hydro turbine using moving particle semi-implicit method," Journal of Computational Science and Technology, vol. 7, no. 2, pp. 338-353, 2013.

35. G. Müller and J. Senior, "Simplified theory of Archimedean screws," Journal of Hydraulic Research, vol. 47, no. 5, pp. 666-669, 2010.

36. E. Fiardi, "Preliminary design of archimedean screw turbine prototype for remote area power supply," Journal of ocean, mechanical and aerospace -science and engineering, vol. 5, pp.30-33, 2014.

37. P. Juliana, A I Weking and L Jasa, "Pengaruh Sudut Kemiringan Head Turbin Ulir dan Daya Putar Turbin Ulir dan Daya Output Pada Pembangkit Listrik Tenaga Mikro Hidro." Majalah Ilmiah Teknologi Elektro, Vol. 17, No. 3, September - Desember 2018.

38. I Kadek Agus Ardika, A I Weking and L Jasa, "Analisa pengaruh jarak sudu terhadap putaran turbinulir pada pembangkit listrik tenaga mikro hidro" ,Majalah Ilmiah Teknologi Elektro, Vol. 18, No. 2, Mei - Agustus 2019.

39. R. Yadav, W. Park, J. Singh and B. Dubey "Do the western Himalayas defy global warming?", Geophysical Research Letters, vol. 3, no .17, 2004.

40. M. Zelenakova, R. Fijko, D. Diaconu and I. Remenakova, "Environmental impact of small hydro power plant—a case study". *Environments*, vol. *5*, no. 1, 2018.

41. R Thakur, S Kumar, K Kashyap, A Kumar and S Aggarwal, "Selection of erosive wear rate parameters of Pelton turbine buckets using PSI and TOPSIS techniques", International journal of innovative technology and exploring engineering (IJITEE), Vol. 9, no.1, pp.2418-2428, 2019.

42. R Thakur, A Kumar, R Nanda and M Sethi, "Correlation development for erosive wear rate on pelton turbine buckets", International journal of mechanical and production engineering research and development (IJMPERD). Vol. 7, no. 3, pp. 259-274, 2017.

43. R Thakur, A Kumar and M Sethi "Experimental examined of effect of silt erosion on overall performance of pelton turbine buckets" IRACST-Engineering Science and Technology: An International Journal (ESTIJ), vol. 7, no.3, pp. 2250-3498, 2017.

44. R Thakur, M Sethi, S Khurana "Impact of sand erosion in hydro turbines: a case study of hydropower plants of Himachal Pradesh, India; Springer nature Singapore: Intelligent Communication control and Devices vol. 624, pp. 1-12, 2018.