Estimation of Hydropower Harvesting from the Hydraulic Structures on Rivers: Ramadi Barrage, Iraq as a Case Study

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**ABSTRACT**

In recent years, Iraq suffers from exacerbation of the deficit of electrical energy as well as the great environmental pollution resulting from the use of traditional fuels. This called for serious thought to search for using clean and renewable energy sources may available in Iraq. In the present study; small hydropower (i.e. Archimedes screw turbine) are specifically used with a low head at Ramadi Barrage in Iraq. This type of small hydropower station is suitable to apply because not need high storage water or high head in Barrage. The power production in this technology depends on the parameters of the location in which it is placed such as (length L, angle of inclination $\alpha$, Diameter $D$, …). The physical model of the Archimedes screw turbine is applied to determine the optimal $\alpha$. The solid work package with a combination of Computational Fluid Dynamics (CFD) analysis by ANSYS have been used to simulate numerically a three dimensions model to determine the value of power that could be produced by the Archimedes turbine in the Ramadi Barrage. The turbine's performance are tested on two cases which represent low and high discharge investigations with different $\alpha$ (18$^\circ$, 23$^\circ$, 30$^\circ$, 35$^\circ$) based on different flow conditions and different water head between upstream and downstream of the barrage. The results showed that the maximum power production from the barrage is 280,000 watts with $\alpha=35^\circ$ and efficiency $\eta=89.9\%$ for case 1; while; this power becomes 400,000 watts with $\alpha=30^\circ$ but of efficiency $\eta=84.9\%$ for case 2. It is concluded from this research that power production from Ramadi Barrage could be investment to eliminate the deficit in the electrical energy in Iraq.

1. Introduction

Because of the exacerbation of the deficit of electrical energy in Iraq; especially in recent years; as well as the great environmental pollution resulting from the use of traditional fuels (oil and its derivatives); this will call for serious thought to search for clean and renewable energy sources that may available in Iraq.

Hydroelectric power is a major source of energy production at the global level. It constitutes about 18$\%$ of electricity production in the world (Hiwatashi, Nakai, and Takemura 1980) and its growth during recent years was slightly higher than the rate of growth of energy demand globally.

According to (UNIDO), there are at least 30 potential small hydropower sites in Iraq available for the small hydropower.

The Iraqi Water Resources Ministry is recently considering and adopting the study entitled ‘Strategy for Water and Land Resources of Iraq’. The aim of this strategy is to develop an integrated plan for investing, managing, and developing the water resources in all Iraqi regions to ensure sustainable management and development of these resources. The utilization of potential hydropower and its investment is an integral part of the study.

According to the UNIDO and ICSHP (2013); Western Asia has the estimated small hydropower potential of about 7,754 MW (for plants up to 10 MW)(Manual, 1998). Some countries in the region do not have any policy for renewable energy such as Iraq, Jordan, and Lebanon, However; for economic and environmental reasons, most of this energy will not be exploited; but; hydropower will continue to develop; as it is the most important source of renewable energy due to it is clean and relatively cheap and requires simple operating costs and production efficiency of approximately 100$\%$ (average production efficiency of conventional and
nuclear fuels are only about 33% (Kamel, et al 2009)); and it is expected that in the next few years the contribution of hydropower to global energy sources may grow faster than global energy production.

Large dams projects are suitable for large hydroelectric plants; but can flood environmental ecosystems. They have very high construction costs, and the difficulty of identifying problems resulting from their operation that can cause unforeseeable disasters when any failure occurs. The demands of societies, farms, and ecosystems based on the river should also be taken into account. The water projects cannot be relied upon in droughts and in long periods of attraction when rivers dry up or flow rate decreases. In last year the climate changes and global warming as well as the dams project in Syria and Turkey have affected negatively on the hydrological cycle and thus on water imports in the region. The small power plants can produce a lot of electricity without the need for large dams. These stations are classified as very small according to the amount of electricity produced. The small electrical systems benefit from the river's energy without diverting a large amount of water from its natural course, in addition to the global trend towards producing clean energy that is not harmful to the environment.

Civil and construction works of the small hydroelectric power stations constitute (21-31%) of the total cost, of building and operating of these stations (Irena 2012). There is a good incentive to invest in existing regulators and Barrages in Anbar Governorate for construction and operating small hydroelectric power stations since these projects (regulators and barrages) are fully constructed and are included to impose water resources management system in the province which means the costs of operating and constructing these units are reduced by up to 30%. In Al-Anbar Governorate, there are many Regulators and Barrages; such as Al-Ramadi Barrage, Al-Fullahjah Barrage, Al-Warar Regulators, Sin Althuban Regulator , Partition regulator- Tigris, and partitioning regulator-Euphrates. (HUSSEIN 2010).

This provides a great opportunity to invest in these systems for the purpose of generating electric energy as part of the system of water resources management in the governorate. In the present study, Ramadi Barrage was chosen as a case study to determine the potential energy that can be generated by small hydroelectric power plants depending on the hydrologic conditions of the river such as discharge and water level.

In recent years; the using of an Archimedes screw turbine; a power turbine; has been introduced to promote the construction of low-head renewable energy, where small hydropower plants have been installed over the past decade in Europe by many industrial companies (Deshmukh et.al, 2017). Archimedes screw turbines are an option for developing countries and this technology does not require operational parts such as other turbines such as screens, feather guide, fish conversion system or garbage tracks (Khan et.al, 2019). This type of turbine is suitable for use at water levels less than 10 m. The water energy generated by this technology is a sophisticated technology suitable for low-attributable hydraulic sites (Maulana and Putra 2019).

(Rorres, 2000) has an analytical method to improve the performance of the Archimedes turbine; where it determines the ratios of engineering parameters such as pitch ratio and radius ratio (Ri/Ro); which is equal to 0.54; where Ri and Ro are inner and outer radius of the screw turbine; respectively.

(Müller and Senior 2009); which based on the Rorres model; they presented a theoretical model of Archimedes screw; where they found that efficiency depends on screw engineering and mechanical efficiency, as well as that efficiency increases with the increase in the number of blades and a decrease in the angle of the screw slope.
2.1 Theory of Power Generated from Archimedes screw turbine:

The power generated using the Archimedes screw turbine, can be calculated as (Nuramal et al., 2017)

\[ P_{\text{Hyd}} = \rho g Q H \]  \hspace{1cm} \text{(1)}

Where,

- \( P_{\text{Hyd}} \) = Hydraulic power in the site units (watt)
- \( \rho \) = water density (kg/m³)
- \( g \) = Gravitational Acceleration (m/s²)
- \( Q \) = flow rate (m³/s)
- \( H \) = water head (m)

Mechanical power generated from screw turbine could be calculated as:

\[ P_{\text{mec}} = T \cdot \omega \]  \hspace{1cm} \text{(2)}

Where,

- \( P_{\text{mec}} \) = Mechanical power generated
- \( T \) = torque of screw (Nm)
- \( \omega \) = Angular velocity of screw (rad/s)

It is calculated:

\[ \omega = \frac{2\pi n}{60} \]  \hspace{1cm} \text{(3)}

\( n \) = rotation of screw in (rpm)

The rotation (\( n \)) of the Archimedes screw in eq.3, can be calculated by equation (4) that recommended by (Nagel 1968), a value that is positioned on the external diameter of the Archimedes screw, which is more suggestive value.

\[ n = \frac{50}{D^{(2/3)}} \]  \hspace{1cm} \text{(4)}

Where; \( D \) = external diameter of the Archimedes screw.

The efficiency of screw turbine (\( \eta \)) can be estimated by the following equation:

\[ \eta = \frac{P_{\text{mec}}}{P_{\text{Hyd}}} \]  \hspace{1cm} \text{(5)}

where \( \eta \) in present.

2.2 The Hydrologic State of Euphrates River

Since 1970s; Iraq received 33 x 10⁹ m³ of water per year from Euphrates River at Hit, 200 km downstream from Husaybah) at the Syrian border. After 1980s; when both Turkey and Syria built a series of large dams on the Euphrates River; the discharge decreased to as little as 8 x 10⁹ m³ per year at Hit as shown in fig.2.

![Fig.2 Euphrates inflow to Iraq (1932-2003)(Ammar et.al, 2013)](image)

For example, the operation of the Ataturk Dam in Turkey after 1991 caused the water input to drop sharply, especially in the years 1991, 1992, and 1993 during which the Ataturk Lake was being filled. Fig.3 shows the effects of new dam’s projects in Turkey and Syria on input water flow to Haditha reservoir especially in period of Ataturk dam operation (1991-1993).

![Fig.3 Effects of dam project in Turkey and Syria on inflow water to Haditha reservoir](image)

After completing the construction and operation of Haditha Dam in 1986, the average discharge of the Euphrates River directly dependent on the release discharges from Haditha Dam. Fig.4 shows the change in river state resulted from Haditha reservoir operation when the average discharge is decreased from 967 m³/s to 553 m³/s. During 2008, the water levels dropped again because of decreases in average precipitation and the presence of many dams upstream the Euphrates River in Syria and Turkey. During these periods the determination of a dry year became highly dependent on the water policy taken by the Ministry of Water Resources.

![Fig.4 Water discharge of Euphrates river at Hit and Haditha cities for the period 1948-2007(Al-Ansari and Knutsson 2011)](image)

However, using previous studies and through analysing the data for the period (1970-2000), the average discharge at Al-Ramadi Station is 640 m³/s, while the maximum discharge was found to be 1279 m³/s at 1988 and the lowest discharge was 247.5 m³/s at 1971. Continue during the period 2000-2020, the average discharge in Euphrates River decreased to about 550 m³/s because of the effects of new dam’s projects in Turkey and Syria as well as climate changes over the world. The minimum discharge was 237.94 m³/s recorded in 2001, while the maximum discharge was 657 m³/s in 2005. (engineering consultant Bureau, 2012).

A statistical study was achieved depending on minimum flow rate during one day during 1985-2008, show there is a probability of 50% for a
discharge less than 213 m³/s. Therefore, in present study, the minimum discharge and maximum discharge of 200 m³/s and 700 m³/s are considered as boundary conditions in numerical modelling to estimate the potential hydroelectric power from the Ramadi barrage. Depending on barrage operation data, the maximum head difference between upstream and downstream Ramadi Barrage is 3.2 m while the minimum head difference is 1 m. The hydraulic conditions of the Euphrates river at Ramadi Barrage is listed in table 1.

| Table 1 Hydraulic conditions at Ramadi Barrage |
| Parameter | Max  | Min  |
| Discharge (m³/s) | 700  | 200  |
| Head (m) | 3.2  | 1    |

2.3 Methodology:

The efficiency of Archimedes turbine depends on many parameters such as L, d, D, α, and H as shown in fig. 5.

![Fig. 5 Parameters of Archimedes turbine (Maulana et al., 2019)](image)

Where:
- L=length of screw; m
- D=outer diameter of screw; m
- d=inner diameter of screw; m
- α=inclination of screw; degree
- H=head of water; m

In present study, the physical model is developed to estimate the optimal values of design parameters that can be used to setup the Archimedes turbine in Ramadi Barrage. The optimal value of design parameters are used as input to numerical model (ANSYS CFD) for power estimation. The predicting of river flow regime includes maximum and minimum discharge and head difference between upstream and downstream of the barrage are also necessary to consider as boundary conditions for numerical model. (table 1). Fig. 6 shows the methodology that is considered in present study.

![Fig. 6 Methodology of the present study](image)

2.4 Physical Model

The physical model has constructed locally from available materials in the hydraulic laboratory of Dams and Water Resources Engineering department-collage of engineering/university of Anbar. Archimedes turbine consists of a hollow shaft made of stainless steel, helixes are discs that have been cut and then welded over the shaft. The blades welded consist of a screw and are surrounded by a casing called the trough. It is a pipe of the mild iron that partially cut from the top; the dimensions are listed in the table 2.

![Fig. 7 physical model of Archimedes turbine](image)

| Table 2 Dimensions of physical model of turbine |
| Parameter | Variable | Value  |
| Screw length | L | 1000 mm |
| Number of blades | N | 1 |
| Inlet diameter | d | 70 mm |
| Outer diameter | D | 130 mm |
| Number of helix | m | 12 |
| Pitch | P | 70 mm |
| Trough diameter | Dt | 134 mm |
| Gap width | Gw | 2 mm |
| Slope | α | 25°, 30°, 35°, 40°, 45° |
In present study, five different angle of turbine installation (25°, 30°, 35°, 40°, and 45°) are tested with physical model to determine the optimal value. Seven different discharges are used for each angle that means the 35 runs are achieved to estimate the power generated. The optimum angle of installation that it gives the maximum generated power is considered as the optimum angle. The results of physical model operation show the optimal angle of turbine installation is 30°-35° (Yulistiyanto et.al, 2012).

2.5 Numerical Model

Geometry is one of the earlier steps needs to be performed before starting the simulation. An Archimedes screw is drawn with SOLIDWORK software. In present study, two cases are tested include different design parameters. Table 3 shows the design parameters for Archimedes turbine used in first scenario with D=2500mm; while; table 4 shows these parameters for turbine in second case with D=4000mm.

The details of the CAD geometry and flow parameters are listed in Table3 and Table 4 for case1 (1250mm) and case 2 (2000mm).

Table 3-Geometrical dimensions and flow parameters with (D=2500mm)- case1

| Type of parameters | Parameter | Value |
|--------------------|-----------|-------|
| Geometrical dimensions | The outer radius of the screw - R_O (m) | 1250mm |
|                     | The inner radius of the screw - R_i (m) | 670mm |
|                     | Screw pitch - S (m) | 700mm |
|                     | Screw threaded length - L_B (m) | 5000mm |
|                     | Number of blades – N | 1 |
|                     | Number of turns-m | 7 |
|                     | The gap between screw a through - S_sp (m) | 10mm |
|                     | The inclination of the screw – α | (18°-35°) |
|                     | The rotational speed of the screw - n (rpm) | (27) |
| Flow parameters | Flow rate - Q (m3.s−1) | 4, 6.5, 10 |

Table 4-Geometrical dimensions and flow parameters with D=4000mm-Case2

| Type of parameters | Parameter | Value |
|--------------------|-----------|-------|
| Geometrical dimensions | The outer radius of the screw - R_O (m) | 2000mm |
|                     | The inner radius of the screw - R_i (m) | 1070mm |
|                     | Screw pitch - S (m) | 1500mm |
|                     | the screw - n (rpm) | 20mm |
|                     | Screw threaded length - L_B (m) | 6000mm |
|                     | Number of blades – N | 3 |
|                     | Number of turns-m | 4 |
|                     | The gap between screw a through - S_sp (m) | 20mm |
|                     | The inclination of the screw – α | (18°-30°) |
| Flow parameters | The rotational speed of the screw - n (rpm) | 20 |
|                  | Flow rate - Q (m3.s−1) | 10, 12, 15 |

The screw geometries were created using a combination of two CAD software packages–Solidwork and ANSYS Design Modeler. First step is the most importantly Solidwork software which is used to draw the geometry of turbine then this drawing is export to the ANSYS. Initially a pair of circles was created, the inner circle representing the inter diameter (shaft), then use extrude tool to constructed shaft off. 5000 mm or 6000mm according to applied case, the outer circle represents the outer diameter and represents the outer end of the blade. After which two casings were constructed; one of which is identical to the outer edge of the blade which is called a domain; and the other represents the outer casing (Trough) after leaving a distance between the blade and the tube of 10 mm which is represents the gap. The full turbine geometry can be shown in fig. 8.

Fig.8 - drawing the geometry of the Archimedes screw turbine model by Solidwork pakage

Next step, is the mesh of the built model which is generated to represent the domain of the solution with specific software that build to generated even structural or unstructured mesh (fig. 9) (Tu, Yeoh, and Liu 2018), a mesh with a tetrahedral element size of 0.05m has been used, and the final result is a mesh formed by 4260852 elements and 877862 nodes; as shown in fig.9.

Fig. 9- Mesh of the drawing model by ANSYS

2.6 Boundary condition

The entrance and exit boundaries of the Archimedes turbine are necessary to be geometrically identical. A steady state flow was used in this as the limit of conditions. Table 5 shows the boundary conditions and domains of the Archimedes screw turbine model.
The generated power of the turbine is obtained from the equation (5). The external diameter of the Archimedes screw will be ready to determine the rotational (n) in eq.(4) that is used to calculate the angular velocity (ω) from eq.(3). Then efficiency of turbine can be determined from eq.(5)

The model is ready to be solved with a defined boundary conditions and defined numerical approach. Final step is the conducting the results of the analysis of the numerical model. The results represent the estimation torque of screw (T) in Nm that it used to calculate the generated power from eq.(2). The pressure change is a phenomenon occurring at the entrance and exit of the turbine where it causes pressure on the blades. The pressure is when cut at the beginning of the blades and then decreases with the distance from the entrance. The pressure difference between the entrance and the outlet of the turbine on the screw blades as shown in fig.10. From this figure; it can be noted that there is a difference in pressure, this difference occurs because of the flow of water that enters the turbine where it enters the blades and then decreases with the distance from the entrance. The pressure difference between the entrance and the output of the turbine is caused by the large collisions on the blades at the entrance.

3. Results and discussion

The pressure change is a phenomenon occurring at the entrance and exit of the turbine on the screw blades as shown in fig.10. From this figure; it can be noted that there is a difference in pressure, this difference occurs because of the flow of water that enters the turbine where it causes pressure on the blades. The pressure is when cut at the beginning of the blades and then decreases with the distance from the entrance. The pressure difference between the entrance and the output of the turbine is caused by the large collisions on the blades at the entrance.

The flow of water is simulated as shown in fig.11. It shows the velocity streamline of Archimedes screw turbine. This velocity at the beginning of the entrance is low because it is not affected by the movement of the blades; and then the speed begins to increase with the movement down on the blades when it contact with blade and then decreases towards the outlet.

Table 5: Parameters at boundary condition

| Fluid Properties | Water Density = 998.2Kg/m³ |
|------------------|-----------------------------|
| Inlet Velocity magnitude = 1-2 m/s |
| Viscosity = 0.001003 kg/m.s |
| Turbulence Model | Standard K-e model |
| slope of screw | 18°, 23 °, 30°, 35° |
| rotation of screw | 20-27 rpm |
| Solid Domain | Aluminum |

Table 6: Power production and efficiency for D=2500mm-Case1

| Flow rate(m³/s) | Head (m) | α | Torque (N.m) | Power (w) | Efficiency % |
|-----------------|----------|---|-------------|-----------|--------------|
| 4               | 2.2      | 18 | 21398       | 60504     | 70           |
|                 | 23       | 24549 | 69410       | 80.4      |              |
|                 | 35       | 25042 | 70804       | 82        |              |
| 6.5             | 2.6      | 18 | 46157       | 130506    | 78.7         |
|                 | 23       | 48932 | 138351      | 83        |              |
|                 | 35       | 50576 | 143000      | 86        |              |
| 10              | 3.2      | 18 | 84140       | 237900    | 75.7         |
|                 | 23       | 93778 | 265150      | 84.4      |              |
|                 | 35       | 99313 | 280800      | 89.4      |              |

Table 7: Power production and efficiency for 4000 mm diameter-Case2

| Flow rate(m³/s) | Head (m) | α | Torque (N.m) | Power (w) | Efficiency % |
|-----------------|----------|---|-------------|-----------|--------------|
| 10              | 2        | 18 | 47173       | 98800     | 50           |
|                 | 23       | 57415 | 120250      | 61        |              |
|                 | 30       | 76394 | 160000      | 81.5      |              |
| 12              | 2.5      | 18 | 85179       | 178400    | 60.6         |
|                 | 23       | 101958 | 213540      | 72.5      |              |
|                 | 30       | 123997 | 259700      | 88        |              |
| 15              | 3.2      | 18 | 148708      | 311453    | 66           |
|                 | 23       | 170741 | 357600      | 75.9      |              |
|                 | 30       | 190986 | 400000      | 84.9      |              |
4. Conclusions

A numerical investigation was done for the availability of using Archimedes screw turbine at river as small hydropower plant. The following conclusion may be done from this investigation:

1. There are good investment potentials to generate electric power through the Archimedes turbine from Ramadi Barrage to reach up to 400 kilowatts per generating unit, and this amount can be used by two or three units to provide energy to the nearby Ramadi hospital with electricity or managing of the Barrage with its energy needs.

2. The highest power obtained from 2500nm diameter is 280800 at a 35º inclination of screw, and more energy can be obtained using a larger turbine.

3. The optimum angle of the Archimedes turbine is 35º in terms of power and efficiency.

4. The power increases by increasing the head and flow rate but it doesn’t always have to increase efficiency due to overflow losses, as the flow becomes above the screw portability and causes leakage losses.

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