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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 α, Diameter D,….). The physical model of the Archimedes screw turbine is applied to determine the optimal α. 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 α (18º, 23º, 30º, 35º) 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 α=35° and efficiency η=89.9% for case 1; while; this power becomes 400,000 watts with α=30° but of efficiency η=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

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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-Fallujah 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.

(Dellinger et al. 2016) presented a theoretical and experimental study, the results of the study showed that The efficiency of the Archimedes turbine is reduced when the angle of inclination is increased. For the screw (Yulistiyanto, Yul, and Lisdiyanti 2012) presented an experimental study on the Archimedes turbine. Parameters affecting the performance of mechanics from the screw turbine is the pitch distance, water discharge and shaft slope. The test results showed that the discharge and shaft slope of turbine effect on power and efficiency.

In paper presented by (Lubitz, et.al, 2014) showed that with a leakage present , a decreasing in the slope of Archimedes screw turbine will cause the head to drop between the buckets due to reduce the amount of flow leakage resulting from pressure difference. As a result, the efficiency of the Archimedes screw turbine will increase with a lower slope angle slope.

In present study, the solid work package with a combination of computational Fluid Dynamics (CFD) analysis by ANSYS have been used to simulate the power can be generated with Archimedes turbine..

2.Material and methods

In the present study; Ramadi Barrage is selected as a case study. It is a diversion dam that includes two sections; namely; northern and southern sections; which constructed on the Euphrates River in 1955s. It is located in the city of Ramadi (Latitude: 33° 26' 2.39" N, Longitude: 43° 15' 33.00" E) in Anbar Governorate about 100km west of Baghdad in Iraq(Al-Hussieny and Ali, 2017); as shown in (fig.1).

The main purpose of the northern section of barrage is to increase water level in the river if needed and allowing it to be diverted water through the southern section of barrage into a canal. It regulates the Euphrates water flow by discharging excess floodwater into Habbaniyeh Lake through Al-Warrar Regulator. It is 209 meters long and consists of concrete structure with 24 opening, each of it is six meters wide, equipped with iron gates that raise and close manually and electrically. The Barrage contains a passage for ships lock 6 meters wide and 40 meters long as well as a ladder for fish. Over the Barrage, a bridge has been built with 7m width to pass heavy transportation. The design discharge of the Barrage reaches 3600 m3 /s at water level 51.50 m at sea level.(Abdullah et.al, 2019).

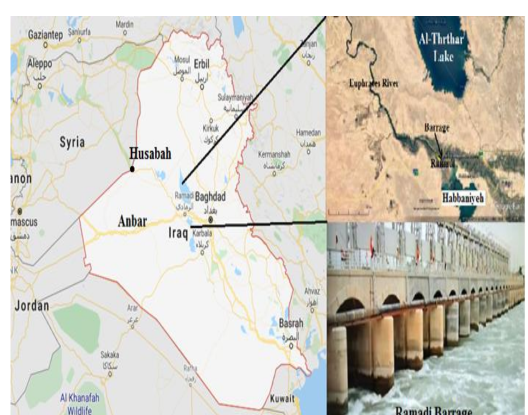

Fig.1 Location of Ramadi Barrage as a case study

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)

$PHyd = \rho gQH$ …. (1)

Where,

PHyd=Hydraulic power in the site units(watt)

ρ=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 calculate as:

$Pmec=T.\omega$ …………(2)

Where,

T=torque of screw (Nm), ω=Angular velocity of screw (rad/s) it is calculated:

$\omega=2\pi n/60$……………(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.

$n=50/D^{(2/3)}$ ……….. (4)

Where; D= external diameter of the Archimedes screw

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

$\eta=Pmec/PHyd$ ……… (5)

where η 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

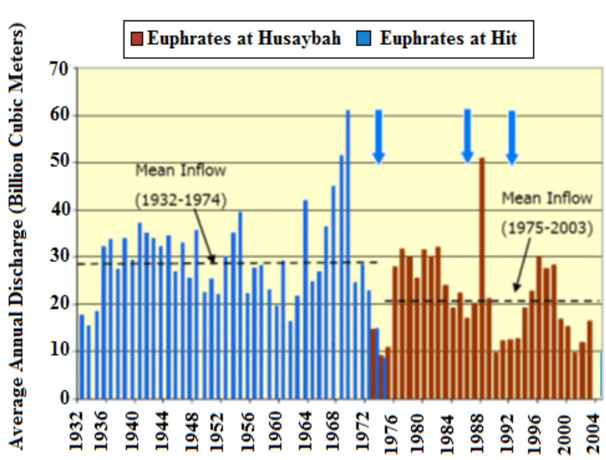

Fig.2 Euphrates inflow to Iraq (1932-2003)(Ammar et.al, 2013)

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

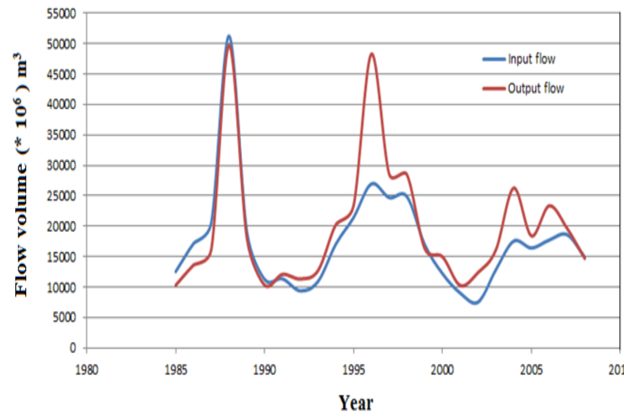

Fig.3 Effects of dam project in Turkey and Syria on inflow water to Haditha reservoir

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 967m3/s to 553m3/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.

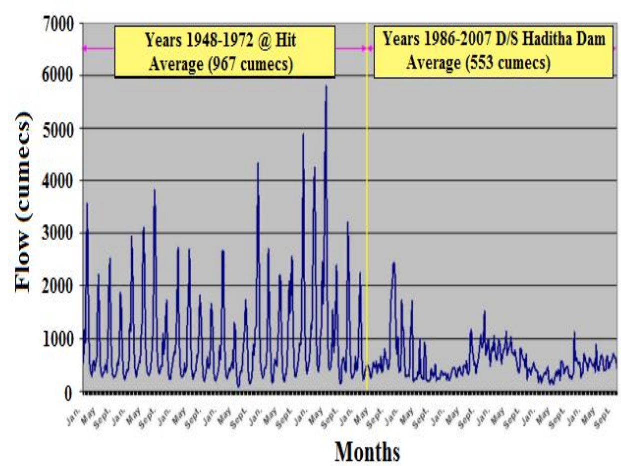

Fig.4 Water discharge of Euphrates river at Hit and Haditha cities for **the period 1948-2007(Al-Ansari and Knutsson 2011)**

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 550m3/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 237.94m3/s recorded in 2001, while the maximum discharge was 657m3/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 213m3/s. Therefore, in present study, the minimum discharge and maximum discharge of 200 m3/s and 700m3/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 3.2m while the minimum head difference is 1m. 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(m^3/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

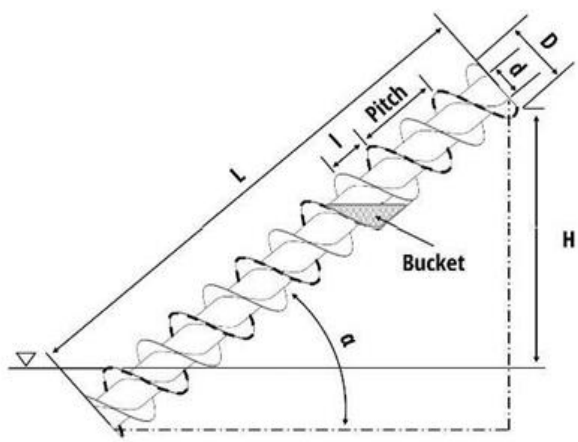

Fig.5 Parameters of Archimedes turbine (Maulana et.al, 2019)

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.

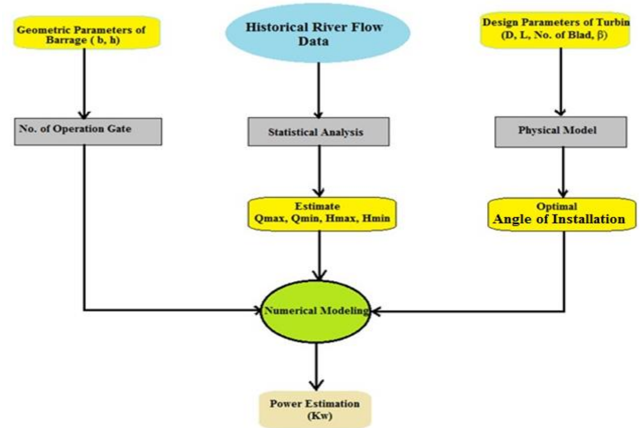

Fig. 6 Methodology of the present study

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 show the turbine physical model that applied in present study.

Fig. 7 physical model of Archimedes turbine

Table 2 Dimensions of physical model of turbine

Parameter	Variable	Value
Screw length	L	1000 mm
Number of blades	N	1
Inlet diameter	d	70mm
Outer diameter	D	130mm
Number of helix	m	12
Pitch	P	70mm
Trough diameter	Dt	134mm
Gap width	Gw	2mm
Slope	α	25º, 30 35º ,40º ,45º

In present study, five different angle of turbine installation (25º, 30º, 35º, 40º, and 45º) 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 30º-35º (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
	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
Geometrical dimensions	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	(18º-35º)
	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 importantantly 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 of(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.

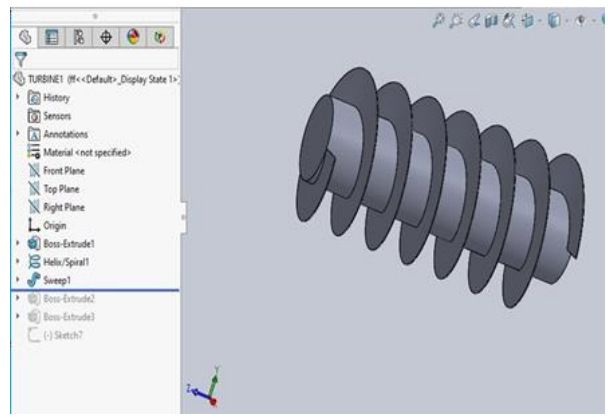

Fig.8 - drawing the geometry of the Archimedes srew turbine model by Soildwork pakage

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.

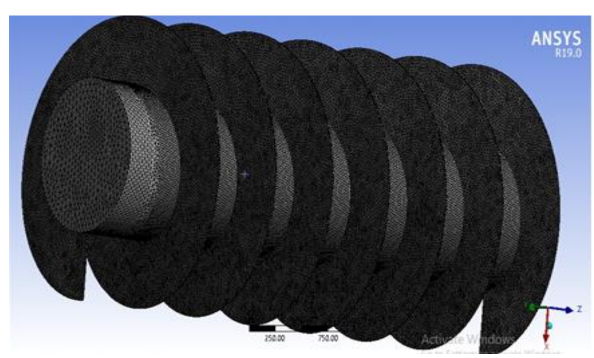

Fig. 9- Mesh of the drawing model by ANSYS

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.

Table 5-Parameters at boundary condition

Fluid Properties	Water Density = 998.2Kg/m^3
	Inlet Velocity magnitude = 1-2 m/s
	Viscosity = 0.001003 kg/m.s
Turbulence Model	Standard K-ϵ model
slope of screw	18º, 23 º, 30º, 35º
rotation of screw	20-27 rpm
Solid Domain	Aluminum

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 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)

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.

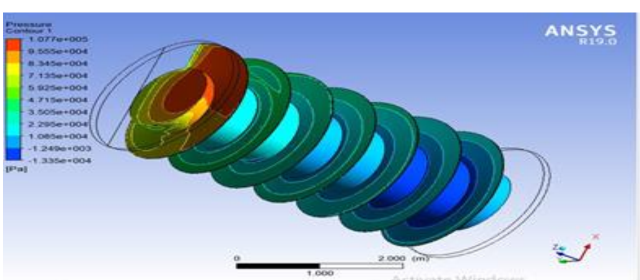

Fig. 10 –Pressure contour at Rotation 27 rpm, v=1m/s, α=23 º

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.

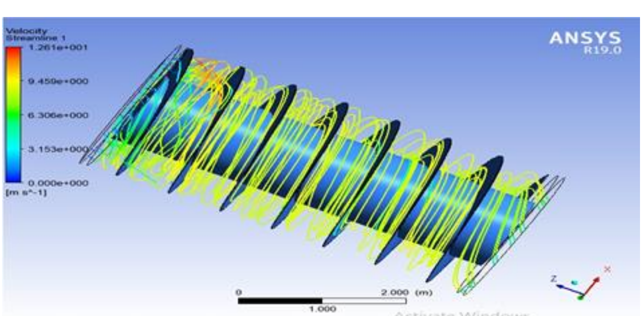

Fig. 11 –Velocity streamline at Rotation 27 rpm, v=1m/s, α=23º

The results obtained are as shown in the tables (6 ,7) as the test was conducted at three different angles, the slope angle was chosen based on the length of the Archimedes screw and the available head (head data and flow rate obtained from the Ramadi dam project management table 1). Table.6 represent the low discharge investigations which held on an Archimedes turbine of 2500 mm diameter, while table 7 represent high discharge investigations which held on an Archimedes turbine of 4000 mm diameter. The results shown in table 6 depict is that the highest energy obtained from 2500mm screw turbine is 280,800 watts at a 35º inclination of screw and at higher value of discharge. From the same table it may conclude that as the angle of inclination become smaller the production of energy decreases .Also highest efficiency attained was at the angle of 35º and this consistent to the result of (Yulistiyanto, Yul, et al. 2012), where his study pointed out that the optimal angle of the Archimedes turbine is 35º.

To determine the effect of greater screw diameter, a 4000mm screw diameter was examined. This diameter may be used at Ramadi Barrage. The results of this diameter are listed in tables (7). the results showed that as the diameter of the screw increases the energy production and efficiency increases. This increase ic accompanied by the increases of angle of inclination. The maximum efficiency of 4000 mm screw turbine was 88% achieved at an angle of inclination 30º while the efficiency was 89.4% for 2500 mm at angle 35º.

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 2500mm 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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