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Numerical and Experimental Study the Effect of Impeller Design on the Performance of Submerged Turbine

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Abstract: *This work presents the design and fabrication of Gorlov helical water turbine. The turbine was tested theoretically and experimentally. For the experimental part open channel was long=1600cm, high=45cm and width=30cm. six water velocity were tested namely (0.86, 1.26, 1.311, 1.51, 1.697 and 1.81 m/s). The results showed that the extracted power increased with velocity. At water velocity of 1.81 m/s, the power produced was 4.621 W. LAPVIEW program was used to control and operate the wind tunnel test bench. Fluent was used to model the turbine and analyses flow around the turbine. Continuity and Naver-stockes equations were solved for a steady, three dimensions and incompressible flow. Turbulence model was tackled by using (k - w The numerical results showed that at 1.81m/s air speed, the power produced was 4.44 W. An agreement was obtained between the experimental and theoretical results.*
Keywords : *Hydrokintic, Hydropower, Gorlov Turbine, helical blade, Renewable energy*

I. Introduction

True renewable energy sources are energy supplies that are refilled by natural processes at least as fast as we use them. All renewable energy comes, ultimately, from the sun. We can use the sun directly (as in solar heating systems) or indirectly (as in hydroelectric power, wind power, and power from biomass fuels). Renewable energy supplies can become exhausted if we use them faster than they become replenished: most of England's forests were cut down for fuel before the English started using coal . ***Amir Bashirzadeh et al.*** [1] investigated power generation by tidal power plant. The case study especially types in-stream tidal generators have been attended firstly and tidal stream power plant across the world and, tidal stream site near to south of Iran, Queshm Island. At the studied site, three bladed horizontal axis axial flow turbines made by Verdant Power Company is attended as in-Stream tidal generators. The reachable energy has been estimated depending on velocity profile of the site for economical parameter have been presented as total benefit to the cost of stream tidal power plant. The concluded the stream tidal power plants is a major solution for energy generation in cost areas as compare with other renewable power generation type. At the end, in agreement with environmental advantages of stream tidal power plants, the generated power using methods, proper solution for optimization of reachable energy from tidal streams and substituting of other power generating resources by tidal stream power plants as a major solution for energy generating in coast areas have been proposed . **Kari Sornes** [2] studied a supple General in the technical water current turbine with a power output of about from 0.5 to 5 kW. The energy flux of the water stream is dependent on the density, cross-sectional area and velocity cubed. A number of different concepts have been developed to utilize this power throughout the world. Because of their low cost and the longevity of micro hydro and there are some developing countries, manufactures and implements technical assistance on the processing of electric power required to small communities in remote areas. Discussions on analysis of performance and display issues beyond the workplace. Reviews current turbine technology most commonly summarized. Narrow band most common small scale hydrokinetic turbine concepts are axial flow turbine and cross-flow turbine. The importance is to produce electric power, whether the turbine inside the ducted or without. Where to put the turbine must be taken into account. Current water turbines, or hydrokinetic turbines, producing electricity directly from the flowing water in a river or a stream . **Taylor Jessica Hall [3]** presented on renewable energy clean, the kinetic energy of water currents in the oceans, rivers, and estuaries studied and considered as a source of unexpected and environmentally beneficial. This research investigated the past flow a cross flow hydrokinetic turbine (CFHT) in which a helical blade turns around a shaft perpendicular to the free stream under the hydrodynamic forces exercised flow. The experiments were run for static ($\lambda = 0$) and dynamic configurations (λ = 1.3, 1.6, 2.0, 3.2, 3.6), and with the turbine in partial (single-blade) and full (four-bladed) configurations. The Reynolds Average Navier Stokes (RANS) equations with a SST-kw turbulence closure model were applied using the commercial computational fluid dynamics software ANSYS FLUENT v12.0. Agreement excellent quality trends are found in the experimental results, and the actual values of the expected stander of good simulations exhibition agreement . **Pete Bachant [4]** studied the development of hydrokinetic turbine test. Singled search for steady measurements of performance of cross flow axis turbines. Explain Turbine performance in waves and Turbine performance in turbulence. Test conducted between two types of turbines are Gorlov Helical Turbine and Lucid Spherical Turbine. And the dimensions of the channel that was carried out the test is Bed Concept test 1.25m x 1.25m turbines up to 3 m/s and Measure brake torque, RPM, stream wise drag. It also illustrates the design part of the test. GHT is a more effective energy converter in simulated open water environment (as expected). LST operates at lower λ due to higher σ. Lower drag, lack of center shaft. Drag coefficients stay fairly constant (good for design); function of λ . **Alessandro Schonborn et al. [5]** presented novel hydraulic control mechanism design for vertical- axis straight bladed Darrieus. Tidal power generation by means of marine current farms is potentially a large renewable energy resource which could be harnessed in many coastal waters. Design include horizontal axis turbine, vertical axis turbines, and devices with oscillating lift surfaces. As the turbine blades rotate the control mechanism enforces acyclic pivoting motion the sinusoidal shape of pitch control movement is continuously variable in amplitude. A towing tank model of the cyclic pitch control turbine was constructed to validate the concept of the control system, and compare the hydrodynamic performance of the cosine control with the classic fixed pitch Darrieus rotor. The model was built for a towing tank and is scaled at 1:15 rotor diameter from the prototype, with 1m rotor diameter. The result show that the efficiency over conventional Darrieus turbine is significantly improve when the turbine operate at low blade tip speed with respect to tidal flow velocity ratio. The Torque coefficient of the Rotor is significantly improved at low values of TSR (Tip Speed Ratio) .

II. Methodology

Turbine and Test Rig Description

The three-bladed, cross-flow helical turbine (Figure 1) is intended for operation in low to moderate currents to provide power for autonomous oceanographic instrumentation deployments. Turbine rotor parameters are given in Table 1.The laboratory test rig consists of an optical encoder to measure angular position used to Tachometer (ω). Flume velocity is controlled by an adjustable recirculation pump frequency. The velocity of the flume measurement by current meter.

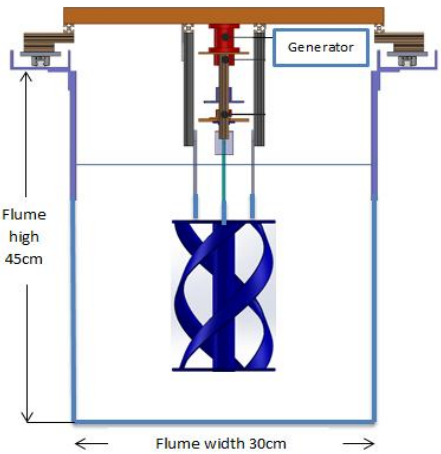


Fig.1. LAB scale turbine and experimental test rig.

Table 1 Parameters of double turbine.

Model 1	parameters	value
	Blade profile	NACA0021
	Number of blades	3
	Turbine diameter (D)	15cm
	Chord of blade	4cm
	Turbine height (H)	20cm
	Helical pitch angle	60deg.
	Blade thickness	0.1cm
Model 2	Blade profile	NACA0021
	Number of blades	3
	Turbine diameter (D)	15cm
	Chord of blade	8cm under 4cm above
	Turbine height (H)	23cm
	Helical pitch angle	60deg. right and 30deg. left
	Blade thickness	0.1cm

III. Numerical solution

The turbine type (GHT) is chosen depending on the levels of the water flow rate in Iraqi rivers, where the data for this information is supplied from the Ministry of Water Resources. The model of turbine is analyzed by using SOLID WORK 2013 and the ANSYS (FLUENT) programs to evaluate its performance. The results is compared with that study by previous author and they showed a good agreement. Because of the complexity of turbine-body configurations and viscous effects, it is difficult to obtain an analytical solution of the Navier-Stokes equation for practical configuration. To demonstrate the effect of turbulence on the flow, a turbulence model that involves the solution of two transport equation (k−w) model is used. The geometry is generated using SOLIDWORKS 2013 and exported to ANSYS Fluent (14.5.7). The average number of cells in this study are (3-4) millions. The Boundary Conditions ,Velocity inlet, Rotating reference frame. It is the maximum number of iterations performed to get the solver terminates. The numbers of iterations are (1500) which are needed in this study. The boundary condition: 1- velocity inlet (0.86m/sec, 1.2 6m/sec, 1.311m/sec, 1.51m/sec, 1.679 m/sec and 1.81m/sec). 2- output pressure is zero equal atmospheric pressure.

IV. Experimental Work and Labview

(a)Experimental work

The experimental rig consists of the following, as shown in figure (2).

Fig.2. Photo and schematic diagram of Experimental test rig.

The dimensions of open channel width 30c m, depth 45c m and length 160cm.The Instrumentations used in experimental work (current meter :is use to measurement velocity of water), (point gage: is use to measurement depth of water in the channel) and the flow measure directly in Controls of channel.

The dimensions of the turbine was chosen to suit the dimensions of the open channel that will be put inside .The turbine Type, designed and fabricated in the commercial market. In the design turbine used dimensions of the turbine section the dimensions section are (see table 1).To manufacture the turbine, an aluminum plate was cut into a rectangle shape, after that the section to make angle 60deg. in all the side of the rectangle plate as shown figure (3).

Model 1 Model 2

Fig.3. The blade of tow model of turbine. And also it is designed piece circular diameter of 15cm in order to connect the three blades. The final shape of turbine as shown figure (4).

Model 1 Model 2

Fig.4. The tow model of turbine.

(b)Lab View

The LABVIEW database connectivity toolset is an add-on package for accessing databases. The toolkit contains a set of high-level functions for performing the most common database tasks and advanced functions for customized tasks [6]. LABVIEW software consists of three parts: the front panel, which is the interface between the program and the user; the block diagram (the program itself) and the icon connector, which is responsible for data flow between routines [7].All the three parts are shown on the pc screen, see figure (5).

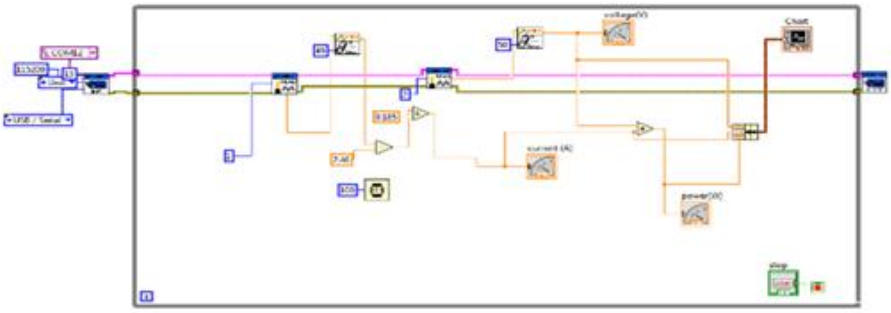


Fig.5. The block diagram of LABVIEW software.

In the work used 1-Current Sensor (ACS712): The Allegro™ ACS712 provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications systems.2- Flow rat sensor: The Flow Rate Sensor measures the velocity of water in a river, stream, or canal. It can be used to study the discharge, flow patterns, and sediment transport of a stream or river. 3-Sensor DAQ: the Sensor DAQ interface provides connectivity between Vernier or custom sensors and a Windows computer running LabVIEW software.To calculate the power of fluid inside channel:

$$Power = \frac{1}{2}\,\rho\, A\, V^3 \ldots\ldots (1)$$

The power (P) transferred between the machine and the fluids:

$$P=T.\omega \ldots\ldots (2)$$

V. Results and Discussion

(a) Experimental results

The velocities, power extracted from the turbine and rotational speeds were obtained at these speeds. Table (1) shows the results obtained.

Table (1): The experimental results

Types of turbine	Velocity of water(m/sec)	Power (watt)	rpm
Model 1	0.86	2.23	37
	1.26	2.26	40
	1.311	2.28	41
	1.51	2.67	43
	1.697	3.11	46
	1.81	3.587	50
Model 2	0.86	2.97	40
	1.26	3.43	43

	1.311 1.51 1.697 1.81	3.75 4.219 4.56 4.621	45 49 50 55

Figure (6) shows the relation between velocity (V) and power output from the turbine. It shows that as V increases, power(P) increases too. This is because the increase in speed entering means increase in kinetic energy entering. Thus the increase in the power of the entry flow increases the power extraction from turbine. Figure (7) shows the relation between velocity (V) and power output from the turbine. It shows that as V increases, torque (T) increases too. This is because the increase in speed entering means increase in kinetic energy entering. Thus the increase in the torque of the entry flow increases the torque from turbine. Figure (8) shows the relation between velocity (V) and kinetic energy. It shows that as V increases, the kinetic energy (KE) increases too. This is because the increase in speed entering means increase in kinetic energy entering and thus the increase in power of the entry flow thus increasing of extracted power from the turbine. Figure (10) shows the variation of Cp with Tip speed ratio λ. It shows that this turbine work properly. Even though the extracted power obtained in this research proved to be of a small scale. However, this turbine is simple to design, easy to manufacture and cheap to produce.

The results of numerical cases, which are the flow field pressure and velocity in the open channel of the turbine, are presented and discussed in this section. The inlet conditions vary under different inlet velocities. Four sections were taken in the turbine region to describe the changes in pressure, and velocity. Figures (11) and (14) show the results of static pressure and velocity magnitude in z-direction when the inlet velocity were 0.86, 1.26, 1.311, 1.51, 1.697 and 1,81 m/s and in the existence of the pressure drop across the turbine. It was found that the pressure distribution inside the system has great experienced variations, among which the pressure drop with turbine area is very large. This is because of the existence of the turbine which causes the pressure drop during the numerical simulation, and the results shown in Fig.11to 12) reflect this effect.

The velocity of the water flow decreases, for which the main reason is that the turbine pressure drop has an inverse effect on the water velocity, as shown in Figures (13 to14) .Also, it is noted that the turbulent flows are significantly affected by the existence of the wall. The near-wall modeling significantly impacts the fidelity of numerical solutions, in as much as walls are the main source of mean vortices and turbulence. In the near wall zone, the solution variables have large gradients, and the momentum and other scalar transports occur vigorously. It can be noted that the speed is minimum in the center of the turbine (stagnation point) as shown in figure (13to 14), but was high at the tips of the blades due to the radial velocity.

The comparison between experimental and numerical results for five cases was done according to equation (3) [8], see figure(9) the results are listed in table (3).

$$E_{ABS} = \frac{|x_{CFD} - x_{exp}|}{x_{exp}} \times 100\% \quad \text{(3)}$$

The results of moment obtained from FLUNET, to calculate the power of turbine, are listed in table (2).

Table 2 the results of fluent.

Types of turbine	Velocity of water (m/sec)	Torque(N.M)	Power (Watt)
Model 1	0.86	0.4321	1.67
	1.26	0.4520	1.89
	1.311	0.4672	2.00
	1.51	0.5041	2.27
	1.697	0.5541	2.67
	1.81	0.5997	3.14
Model 2	0.86	0.5321	2.23
	1.26	0.5872	2.64
	1.311	0.6305	2.97
	1.51	0.7201	3.69
	1.697	0.7531	3.95
	1.81	0.7712	4.44

Table 3 Comparison results of power.

Types of turbine	Power(watt)		Error (%)
	Numerical	Experimental	
Model 1	1.67	2.230	25.11
	1.89	2.260	16.37
	2.00	2.280	12.28
	2.27	2.670	14.98
	2.67	3.110	14.15
	3.14	3.587	12.46

Model 2	2.23 2.64 2.97 3.65 3.95 4.44	2.970 3.430 3.750 4.219 4.560 4.621	24.9 23.03 20.8 13.48 13.38 3.92

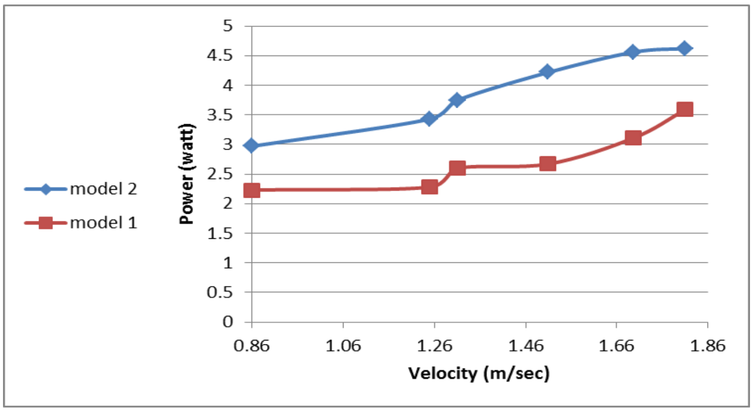


Fig.6. The relation between output power and velocity.

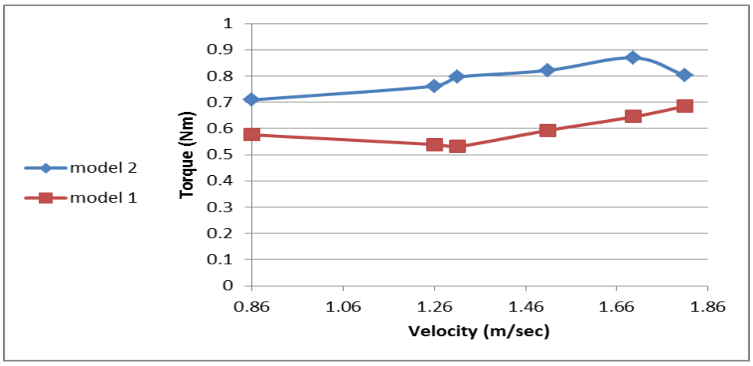


Fig.7. The relation between Torque and velocity.

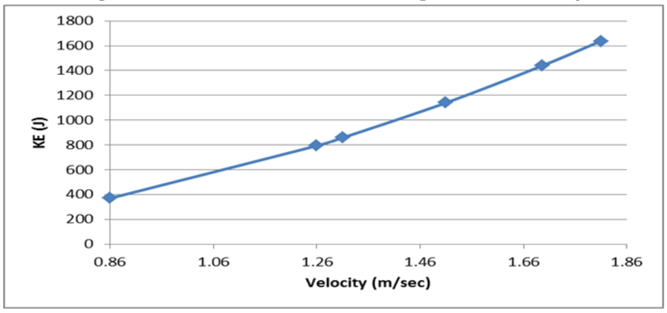
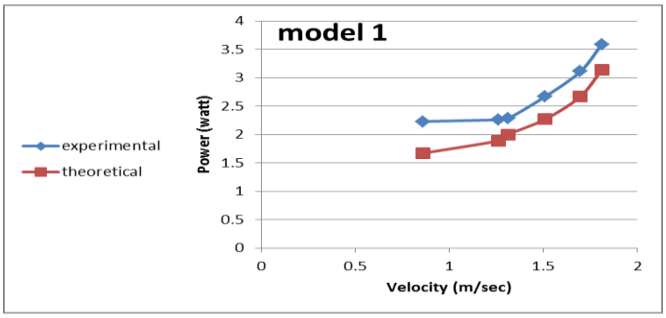
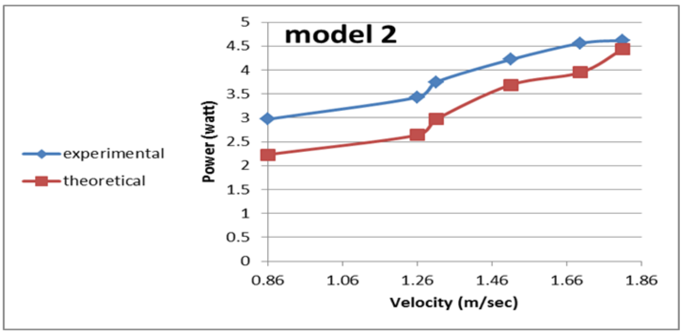


Fig.8. The relation between kinetic energy and velocity.

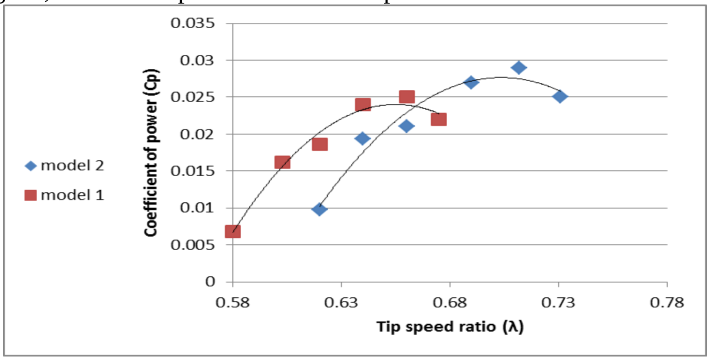


(a)

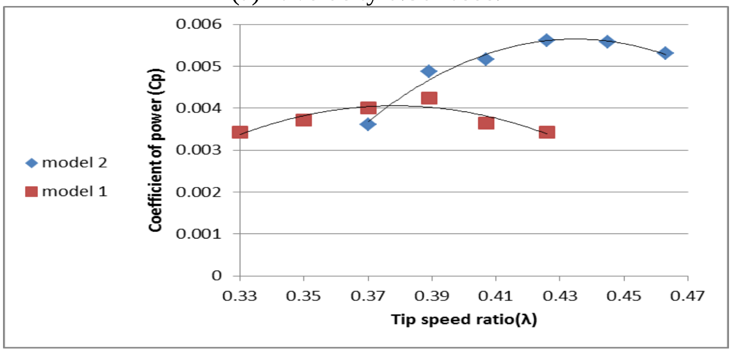


(b)

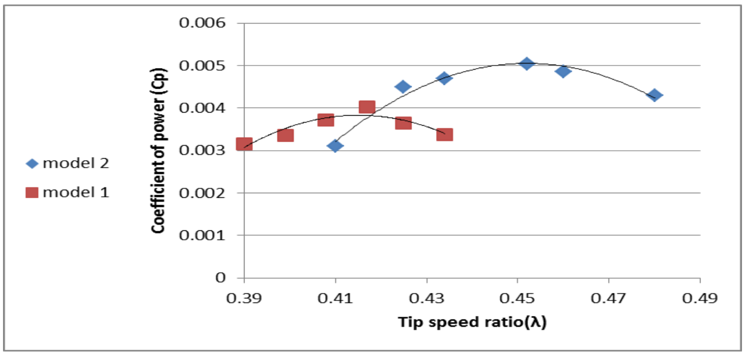
Fig.9 a, b. The comparison between experimental and numerical results.



(a)At velocity 0.86m/sec.

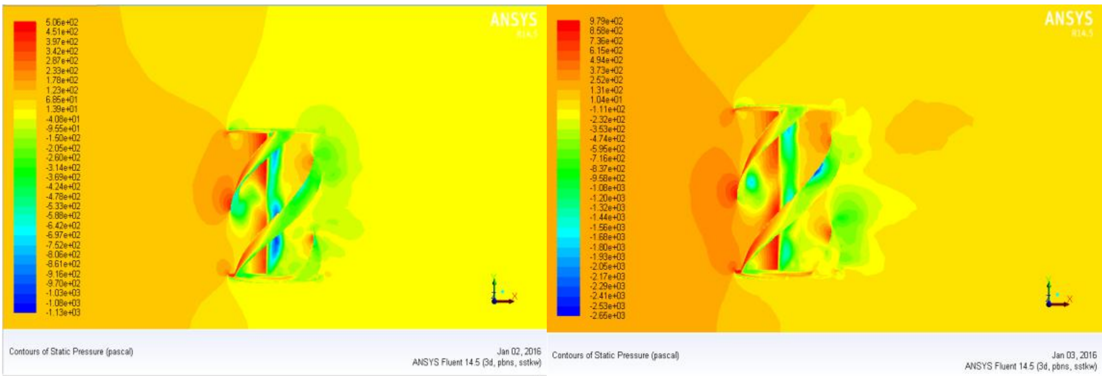


(b)At velocity 1.31m/sec.

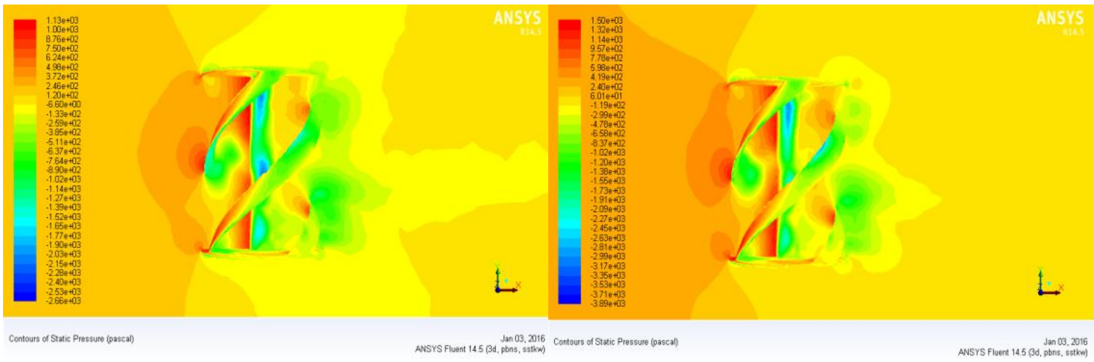


(C)At velocity 1.81m/sec.

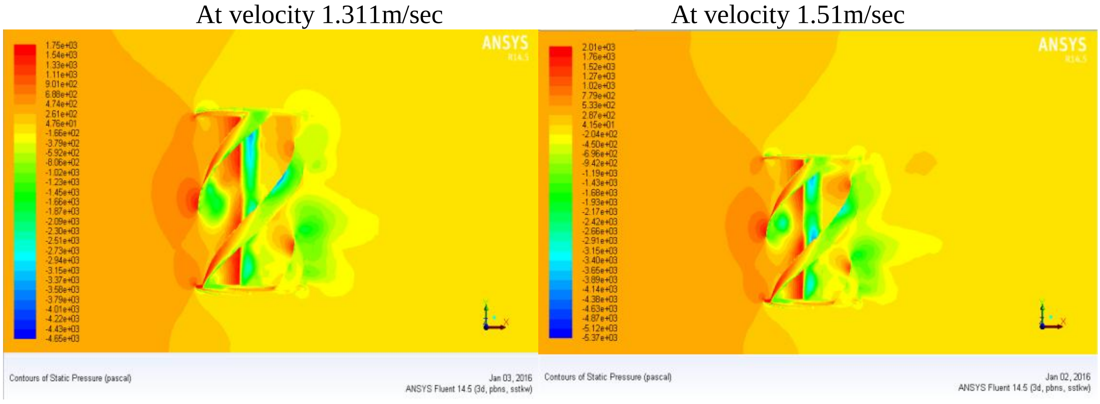
Fig.10 a, b, c. The relation between Tip speed ratio and coefficient of power.



At velocity 0.86msec At velocity 1.26m/sec

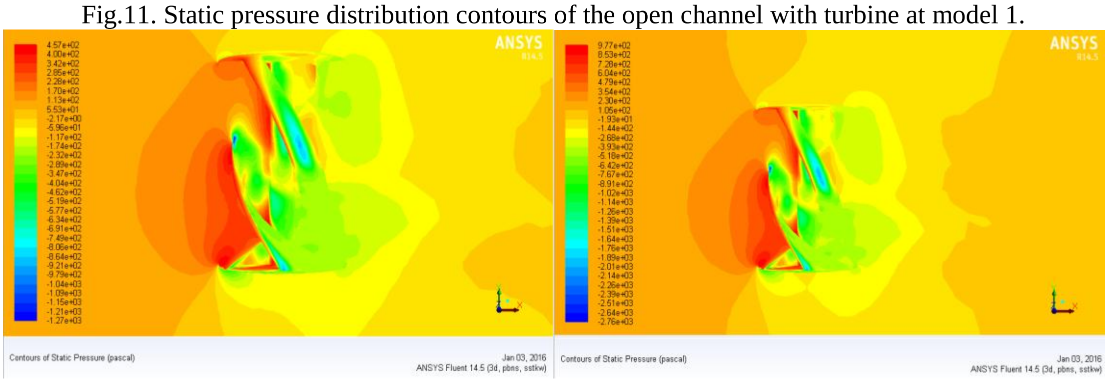


At velocity 1.311m/sec At velocity 1.51m/sec

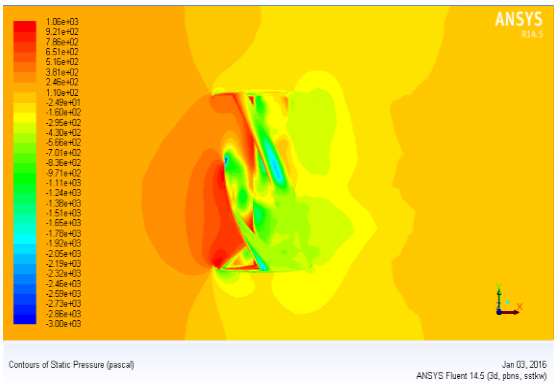


At velocity 1.697m/sec At velocity 1.81m/sec

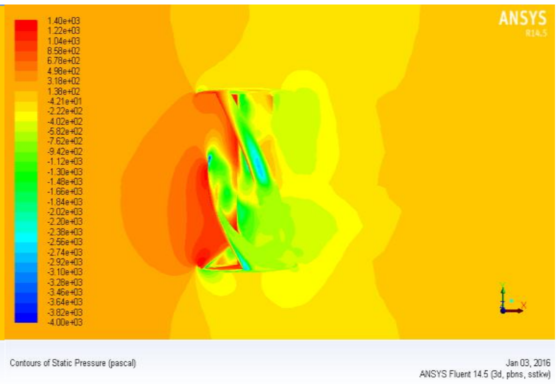
Fig.11. Static pressure distribution contours of the open channel with turbine at model 1.



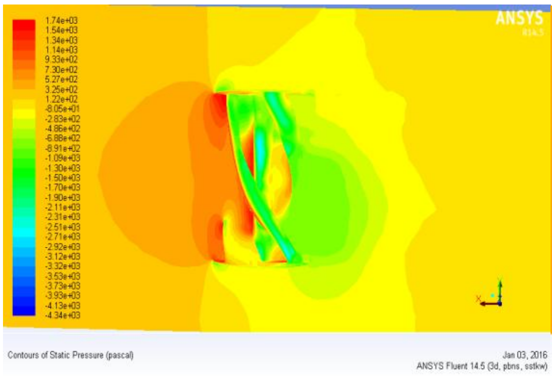
At velocity 0.86m/sec At velocity 1.26m/sec



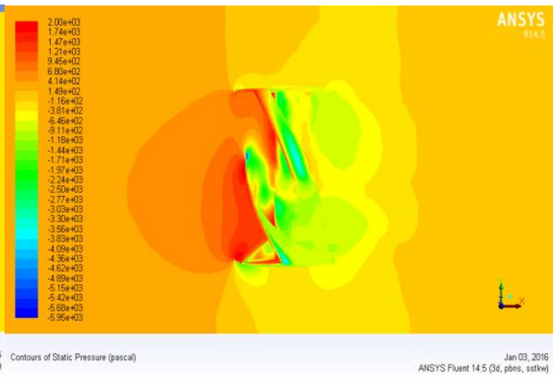
At velocity 1.311



At velocity 1.51

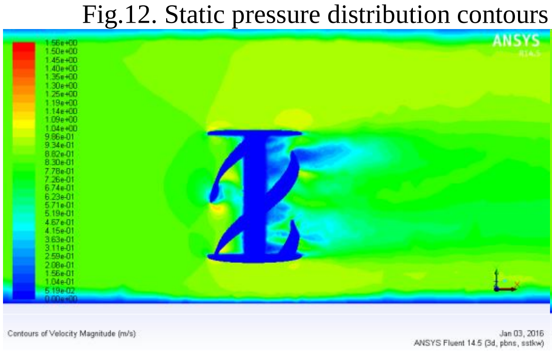


At velocity 1.697

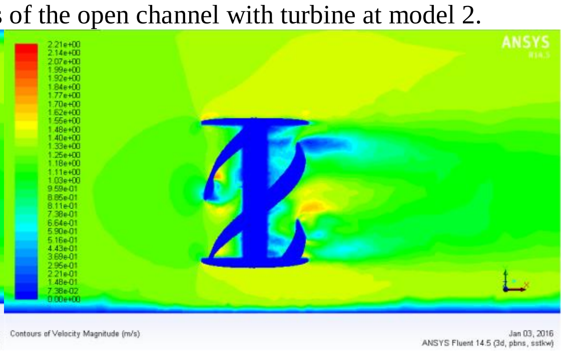


At velocity 1.81m/sec

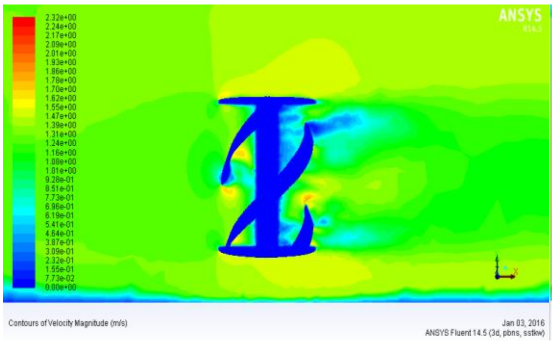
Fig.12. Static pressure distribution contours of the open channel with turbine at model 2.



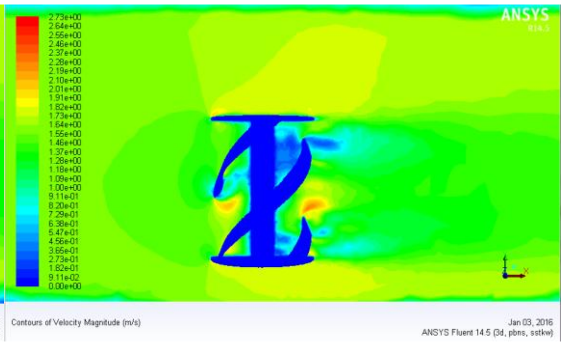
At velocity 0.86 m/sec



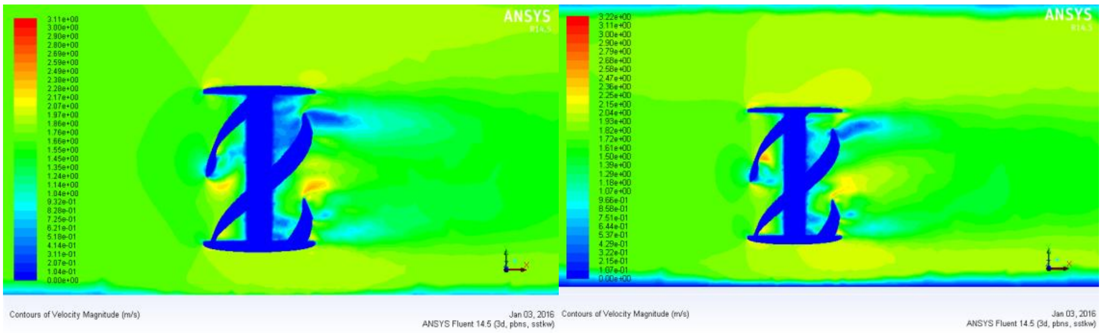
At velocity 1.26m/sec



At velocity 1.311 m/sec

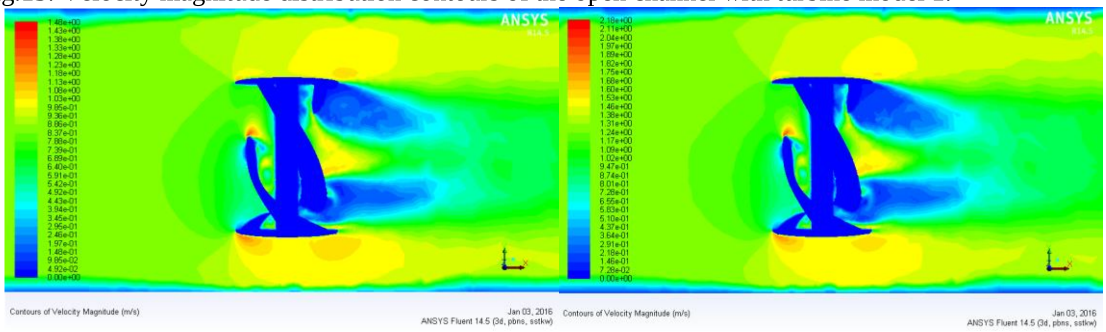


At velocity 1.51 m/sec

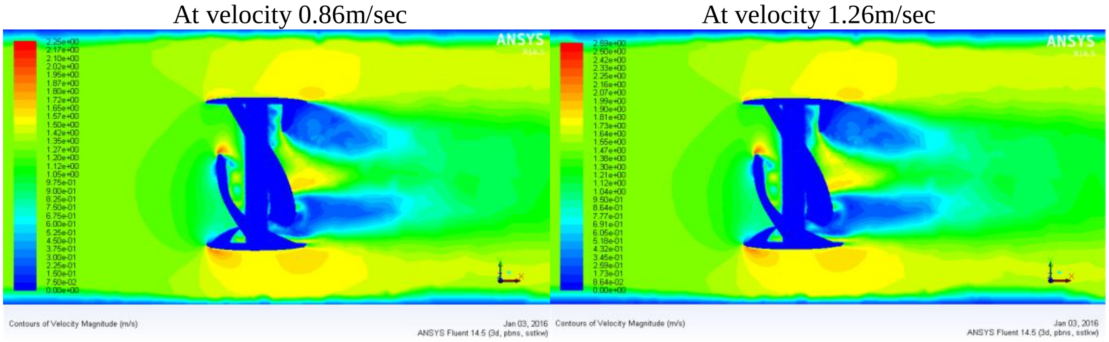


At velocity 1.697 m/sec At velocity 1.81 m/sec

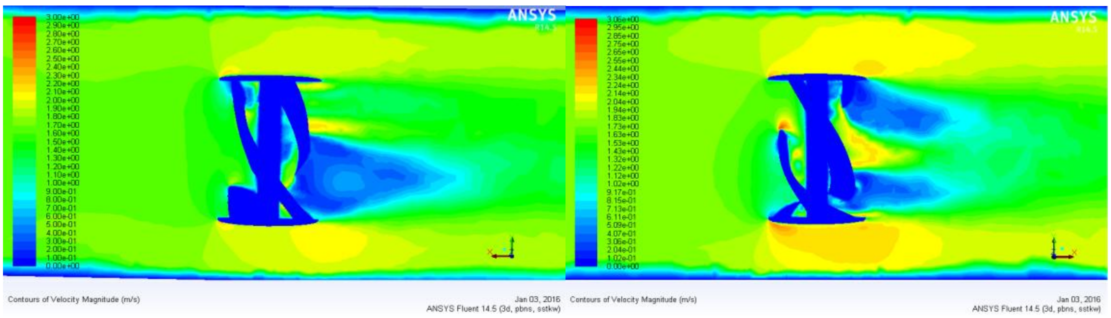
Fig.13. Velocity magnitude distribution contours of the open channel with turbine model 1.



At velocity 0.86m/sec At velocity 1.26m/sec



At velocity 1.311m/sec At velocity 1.51m/sec



At velocity 1.697m/sec At velocity 1.81m/sec

Fig.14.Velocity magnitude distribution contours of the open channel with turbine model 2.

VI. Conclusions

The experimental and numerical results obtained proved that this turbine was properly provided that a channel is provided. However, the following conclusions can be drawn:

1- This turbine works properly but requires a channel to enhance power extraction.
2- Turbine with tips proved to work better than that without tips, It is the tips worked as guide vanes to direct water flow.
3- LABVIEW was used successfully in this work to control the whole experiments.
4- Numerical and Experimental results agreed well.

5- Power extracted is function of water velocity. It is still of small scale. However, to get power of useful scale, fields of turbines are required.

VII. Recommendations

The following recommendations are made for future works:

1- Use different materials like fabric to construct the turbine.
2- Use different turbine sizes to get an optimum size.
3- Use different turbine blade (pockets) number and design to get at the best design.
4- Study the work and performance of this turbine for other river (Tigris) in Iraq.

Notations

Latin Letters		
Symbol	**Definition**	**Unit**
ρ	Density	kg/m^3
A	Swept area of the rotor	m^2
V	Velocity of water	m/sec
P	Output power	Watt
T	Torque	Nm
KE	Kinetic Energy	J
Abbreviations		
CFD	Computational Fluid Dynamics	_
SST	Shear-Stress Transport References	_

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