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INTRODUCTION AND LITERATURE REVIEW ON ATBARA WATER CURRENT TURBINE MOUNTED ON BUOYANT DECKS PLATES

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ABSTRACT: The motivation that led to the writing of the present paper is the necessity to exploit the high velocity energy of River Nile that obtained when River Atbara meets River Nile in Atbara city, which is located in River Nile State. At the junction of the two rivers, high velocity energy is available and therefore, could be utilized in different applications. A suitable energy converter is needed to utilize this abundant energy. The water current turbine unit is mounted on buoyant decks plates' pontoon. This review paper is a continuation of a series of researches executed by the Faculty of Engineering and Technology Atbara – Nile Valley University to utilize the hydraulic energy of River Nile and try to convert it into a suitable form of energy for the general good of the simple citizens of River Nile and Northern States. The review study includes general introduction to water current turbines; literature review; theories of aerofoils, which include aerofoils definitions, aerofoils terminologies, geometrical parameters of aerofoils, aerofoils types; generation of lift and drag; and conclusions.

KEYWORDS: Aero foil sections, Flowing rivers water turbines, Efficiencies, coefficient of lift and drag

1 INTRODUCTION

The water-current turbine, originally designed to harness the energy of the Nile to irrigate the deserts of Sudan, can function when water levels are too low for gravity to do its work. It does not need a full-time operator, but can be controlled by a single, unskilled farm laborer with minimal training. In addition, it has other advantages as well: it involves no large-scale civil engineering, uses no fuel or oil, causes no pollution and provides a continuous, 24 hours per day operation.

The design, intended to compete with the single-cylinder diesel-powered pumps widely used for irrigation in less developed regions, British consultants Peter Garman and Barbara Sexon won the citation for Appropriate Technology in the United Kingdom Better Environment Awards for Industry three years ago. Since then, more field tests have been carried out in Egypt and Somalia, as well as Sudan, and plans have been prepared for manufacture of the turbine in small workshops, starting this year [1].

The water-current turbine is the underwater equivalent of the windmill, making use of the kinetic energy in the moving water just as a windmill does of the wind. It has a three-bladed rotor connected by belts to a centrifugal pump floating on a buoyant decks plate's pontoon. pontoon above the waterline. A typical site would be a private farm with about three hectares of land close to the riverbank.

It is essential that before ordering a machine the farmer determine the river depth and speed and the height of the bank where the turbine is to be installed so its design can be tailored to the operating site. Because river levels vary considerably throughout a year, it is important to know the minimum flow. The depth, speed and height will govern the mechanical shaft power that could be obtained, the transmission ratio needed and the pump to be used [1].

The turbine is simple to construct, and almost all the materials needed are available in local markets. The transmission belts and pulleys and the pump have to be imported, but the rest of the turbine is fabricated from metal strip, angle, rod and bar. It can be delivered to isolated locations in a small truck and installed without machinery. The only civil engineering needed is the installation of a mooring post on the bank [1].

In field tests on cooperatively farmed land that situated around Atbara in Northern Sudan, the turbine pumped 30 cubic meters of water an hour (8.5 1/s) to a height of seven m in a river speed of 1.1 m/s. Another 11 research and development turbines were installed in Southern Sudan and the first locally made machines were due in Sudan this year. FAO provided funding for a single demonstration turbine at a private farm on the river Jubba in southern Somalia. Moreover, under a demonstration project carried out by ESD Ltd. of Britain and the Egyptian government, two turbines were manufactured in the United Kingdom for installation near Cairo to encourage local manufacture [1].

The United Kingdom price is US$12 000 a pump ex works, less than an equivalent solar or wind-powered pumping system but more than a diesel- or electric-powered pump. If the turbine materials were imported by development banks at the same favorable rates as the diesel pumps, the cost for a locally manufactured turbine-pump would still be about one-and-a-half times that of a diesel pump. However, because there is no expenditure for fuel and maintenance and repair costs are low, the farmer would break even after one to two years of operation, and save money after that.

Peter Garman, who has been working with farmers in Northern Sudan, reported that he found them initially dubious about such a new technology. However, as they become familiar with the turbine and see its capabilities, they are becoming more enthusiastic and have increased the area of farm under cultivation. The farmers have passed along news about the turbine, and this has led to a series of unsolicited requests for machines. Adding to their interest was the government's removal of subsidies on diesel fuel, which resulted in a dramatic rise in the cost of diesel-powered irrigation.

Two other kinds of water-powered engines are also available - the Plata Pump and the Chinese turbine-pump: The Plata Pump which was invented in New Zealand, went on the market a decade ago at a price of about US$2 000. Although useful, it appears to be less efficient and robust than other turbine-pumps [1].

The pump has a series of small turbine rotors that are mounted on a single shaft along the axis of a cylindrical duct, approximately 2.5 m long and 0.5 m in diameter. It is like a multi-rotor propeller turbine, although there are no diffusers or other static blades to control rotation of the fluid. The shaft drives two opposed single-acting piston pumps via a crank.

The Plata Pump is intended to be mounted in a low dam or weir so that it slopes at a slight angle and water runs downhill through it. It works best when running around two-thirds to three-quarters full, probably because when running at full capacity the flow rotates and causes loss of efficiency.

The machine is designed to operate on heads of 0.25 - 1m. This is engineered by placing the Plata Pump at an angle on a streambed and building up a weir with rocks or other material to create the necessary head. The overall efficiency of the Plata Pump has been measured in the range of six to 30 per cent at delivery heads from 6 to 90 m. The best efficiency was recorded at a 24 m head.

The Chinese turbine pump have taken the combination of turbines and pumps to a logical conclusion by producing a large range of integrated turbine-pump units. Chinese turbine pumps are generally used for low head applications where the hydropower source will often be a canal jump in an irrigation scheme or a weir on a canalized river giving a head in the region of one to 15 m.

The turbine most commonly used is a fixed-pitch propeller turbine, appropriate for low heads. This is usually mounted with a vertical shaft surrounded by fixed gates, which means it tends to be at its most efficient only over a narrow range of flow rates. A centrifugal pump impeller is mounted on the same shaft as the turbine, back-to-back [1].

Small manufacturers in China make a large variety of different sizes and models of turbine pumps at low prices for the export market. The smallest size pump costs US$89, has a net weight of 59 kilograms and a discharge of 6 to 12 l/s. The irrigation cost is US$5 - 15/hectare, compared to US$35 - 90/ha for electrically energized pumps and US$70 - 130/ha for engine pumps.

The increased consumption of energy resources year after another, has been threatening our globe since the inception of the industrial revolution at the beginning of the nineteenth century. The invention of engines and machines have been followed by drilling the ground searching for oil and other mineral resources. This eager and crazy race of trying to possess the available forms of energy by any means, and to convert it into products and/or services for the welfare of human beings encourages the scientists and researchers to do their best in order to save the world limited resources from replenishment. Therefore, the scientific research was directed towards finding other resources of energy, which must be continuous and eternal i.e. renewable energy like solar, wind, biological, gas, underground latent heat, and water-current energy. These forms of energy can be utilized with very small or approximately no running cost to solve completely or partially the energy problems in many countries throughout the world. Now the problem is the elevated initial cost of constructing the converting units, which is capable of changing these raw energy sources into useful forms [1].

2 LITERATURE REVIEW

The utilization of water-current power was started in the first century, where the river's water-current was used to power under-water mill for crushing corn. The first mill was used in the fourth century in the Middle East with a horizontal shaft, and then it was developed to have a vertical shaft. At the beginning of the industrial revolution, the mill was used in Europe and the United States for pumping water and woodcutting. The less well – known method of extracting energy from tidal and other flows is to convert the kinetic or velocity energy of moving water directly to mechanical shaft without otherwise interrupting the natural flow in a manner similar to a wind turbine. This idea is not completely new as it has been investigated by Reading University in the U.K. in 1979 [1], by Davis in Canada [2] and by Hilton in Australia at about the same period [3]. It was in use in Africa on a small scale in the early 1980s to extract energy from river currents [1]. However, the idea of using current flow on a large scale is new. Even as recently as 1991, a complete book on tidal energy made no mention of the concept [4]. It is only now that this concept is being explored for larger scale use [2], [5], [6], [7], [8], [9], and [10].

Direct conversion of kinetic energy by a turbine in open flow harnesses less of the total available energy in a tidal flow in an estuary than could be extracted by damming the whole estuary. However, direct conversion has several advantages:

1. The capital cost of civil works is eliminated.
2. Disruption to ecosystems and boating traffic is minimized.
3. Ocean currents, wind induced currents and river flows as well as tidal flows can be used.

Here in Sudan, all the above-mentioned types of renewable energy are widely and abundantly found, but the appropriate technology of exploiting them has not yet been introduced.

The natural power of a running river or a stream has been of interest for electricity production for many years. The technology of small-scale hydropower is diverse, and different concepts have been developed and tried out [11] – [17], i.e. water current turbines with a unit power output of about 0.5–5 kW. These turbines are supposed to be used for domestic electricity applications such as lighting, battery charging, and small refrigerators and for small pumping units. The units are small, cheap and often owned, installed and used by a single family.

Water current turbines have received a growing interest in many parts of the globe. Two main areas where these turbines can be used for pumping and/or power generation purposes are tidal currents and river streams. This book will focus on water current turbines for river applications. These turbines generate power from the kinetic energy of a flowing stream of water without the use of a dam. Water current turbines can be installed in any flow with a velocity greater than 0.5m/s [18], [19]. Because of low investment costs and maintenance fees, this technology is cost effective in comparison to other technologies. This kind of small-scale hydropower is considered environmentally friendly, meaning that there are no toxic emissions as that exhausted from diesel engines. Small-scale water current turbines can be a solution for pumping purposes and power supply in remote areas [20].

The kinetic energy of water-currents of river is a reliable energy source for operating mills, pumps, electrical generators etc... A current speed of (one m/s) represents an energy flux of 500 watts per (m^2) of river cross-section. Attempts to utilize this energy for pumping purposes were initiated in 1975 at Mechanical Engineering College Atbara (MECA) through students' final year project. The idea of this project was to design and create experimental data of a piston pump driven by a floating water wheel mounted on buoyant decks plates pontoon. After several attempts during the last twenty years, a successful approach has been reached, where a completely submerged three- blades turbine driving ordinary centrifugal pump through speed increasing transmission is used, which is known afterwards as water - current turbine.

The water current turbine that was designed and constructed in the Faculty of Engineering and Technology, Nile Valley University - Atbara is an energy converter, used to convert the kinetic energy of water currents into mechanical energy, which in turn used to drive a centrifugal pump for irrigation purposes. This unit is composed of a rotor with three blades coupled to a shaft which transmits power to a centrifugal pump through a simple transmission system "pulleys and belts" as shown in figure 8. Water is pumped from the river to the irrigation canal on the riverbank through a rigid pipeline, which also acts as an access walkway to the machine. All this arrangement is carried on buoyant barrels closed at both ends and connected by steel frame or bed. This unit develops about 1000 watts with an overall efficiency of 24 percent and costs about 6 million Sudanese pounds (i.e. fifteen thousand pounds in today's price), the initial cost of the construction of this unit is relatively high compared with Lister diesel engine for the same output power. This induces the idea of this project in order to improve the ratio of power developed per initial cost through modifying the previous design of the whole system using the following procedures:

There are two areas, which can be investigated to comply with the modified objectives.

i. To establish data of performance concerning Atbara water-current turbine for the first time i.e. to determine speed and torque for different angles of attack for the two proposed types of aerofoils, the straight – cambered and the cambered – cambered aerofoils.
ii. To propose some changes in Atbara water-current turbine in order to improve the existing designs.

3 THEORIES OF AEROFOILS

3.1 Aerofoils definitions

An aerofoil is a streamlined body designed to produce lift with minimum drag. In a streamlined body, immersed in a flowing fluid, separation is delayed until near the rear. This will decrease the drag on the streamline body to a minimum value. The drag on a streamline body can be as low as 1/15 of that on a cylinder of the same thickness.

The most important feature is the slowly tapering tail. This is the reason why streamlining of a railway engine with a train behind it makes only marginal difference. On the other hand, it is essential to their performance that the wings and fuselage of an aeroplane and the parts of a sub-marine should have streamlined profiles. It is also apparent that the shapes shown in figures1 and 2 resemble the shape of many marine creatures i.e. fishes, dolphins etc… (Refer to references [21] – [34]).

3.2 Aerofoils terminologies

Figure 1 shows a typical aerofoil section and some of the terms relating to it. These terms are as follows:

Leading Edge: It is the edge, which faces the direction of flow firstly and sometimes referred to as a nose.

Trailing Edge: It is the far edge of the rear edge of an aerofoil.

Chord: It is the distance between the leading edge and the trailing edge points.

Chord Line: It is the straight line drawn to connect the two edges together.

Camber Line: It is the line connecting the two edges so that it should pass through the centroid of an aerofoil.

Angle of Incidence: It is the angle at which the chord line of an aerofoil makes with the direction of flow and sometimes referred to as the angle of attack.

3.3 Geometrical parameters

The characteristics of any aerofoil section are largely determined by some geometrical parameters. These parameters are:

(t/c) Ratio: It is the ratio between the maximum thickness (t) and the chord line (C).

(x/c) Ratio: It is the ratio between the position of the maximum thickness of the nose and the chord length.

Percentage Camber: It is the ratio between the maximum camber and the chord length (as a percentage).

Percentage Nose Radius: It is the nose radius of curvature as a percentage of the chord length.

Trailing Edge Angle: It is the angle between the upper and lower surfaces at the trailing edge.

3.4 Aerofoils types

Aerofoils are generally classified into two types; symmetric and asymmetric aerofoils.

3.4.1 Symmetric Aerofoils

The main feature in this type of aerofoils is that the camber line coincides with the chord line as shown in figure 2. These aerofoils are rarely used in practice since higher values of lift and other types of aerofoils can still obtain lower values of drag.

3.4.3 Asymmetric aerofoils

The ratio between lift and drag (L/D) can be improved by using asymmetric aerofoils. In the aerofoils the camber line does not coincide with the chord line as shown in figure 1, the simplest form of asymmetric aerofoils is called cambered aerofoils in which the camber line is made into a circular arc. In cambered aerofoils both faces can be made curved in one direction or the top face curved while the bottom face is straight as shown in figure 3 {(a) and (b)}.

4 GENERATION OF LIFT AND DRAG

If an aerofoil is placed in a stream of a flowing fluid, the streamlines around the aerofoil will be deflected resulting in a decrease in pressure on the upper surface and an increase in pressure on the lower surface. Due to this, difference in pressure a force is generated which may be resolved into two components: a component parallel to the direction of flow giving the drag force (D), and a second component normal to the main stream giving the lift force (L) as shown in figure 1, both lift and drag forces are substituted in terms of the maximum dynamic force $(\hat{F})$ which is given by the formula:

$$\hat{F} = \frac{1}{2}\ell\, u_o^2 A \quad (N) \tag{1}$$

Where; ℓ = water density in (kg/m^3).
u_o = relative velocity between the flowing fluid and the body in (m/s).
A = projected area on the chord line in (m^2).

The lift force is:

$$L = \frac{1}{2} C_L \ell\, u_o^2 A \quad (N) \tag{2}$$

The drag force is:

$$D = \frac{1}{2} C_D \ell\, u_o^2 A \quad (N) \tag{3}$$

Where: C_L = coefficient of lift.
C_D = coefficient of drag.

The ratio (L/D) or $\{C_L/C_D\}$ is very important and it depends on the angle of incidence (α) and other geometrical parameters.

The best angle of incidence is one, which gives maximum value of $\{C_L/C_D\}$. With increase of angle of incidence from zero, the suction (negative pressure) increases over the upper surface, particularly towards the leading edge and with it the lift increases. However, at a sufficiently high incidence the adverse pressure gradient following the peak approaches a value for which boundary layer separation develops. With further increase of incidence, the flow separation rapidly spreads over the upper surface, and the peak suction falls. In this case, over the region of the separated flow the pressure becomes more nearly constant over the surface whilst the trailing edge pressure and the lift fall. The wing is then said to be stalled.

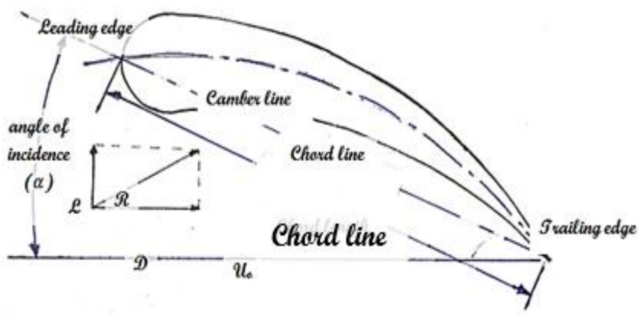

Figure 1. Asymmetric aero foil

The performance of any aerofoil blade can be drawn in a graph showing the variations of lift coefficient (C_L) and drag coefficient (C_D) with the incidence angle (α). Figure 4 shows atypical variations of coefficient of lift (C_L) and coefficient of drag (C_D) with angles of incidence (α).

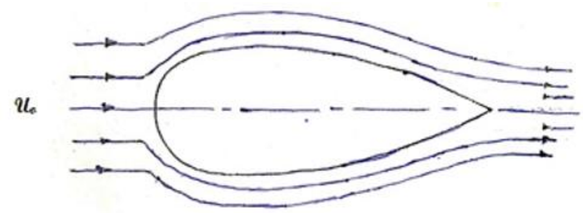

Figure 2. Symmetric aero foil

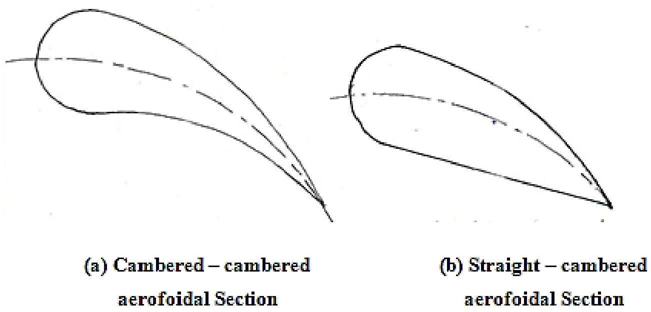

Figure 3. Two types of aero foil section profiles

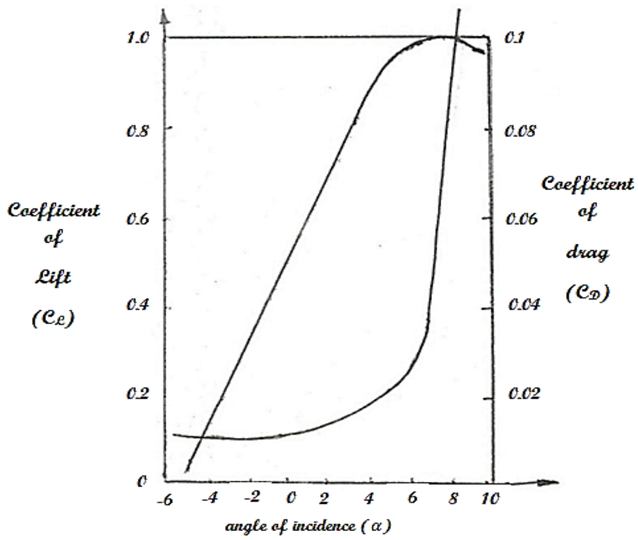

Figure 4. Variation of C_L and C_D with α for a typical aero foil of cambered – Cambered aero foil

5 CONCUSIONS

The common factor in all rotodynamic machines, is that the fluid is fed to the runner or rotating element continuously in such a way that it has a tangential velocity component (or velocity of whirl) about the axis of the shaft as it enters the runner and emerges radially or axially having lost its tangential momentum and exerted a torque on the runner in the process.

In the water-current turbine, three or more blades of aerofoil section profile into kinetic energy convert the hydraulic energy of the fluid supplied to the machine, and this happens because of the high difference in pressure created due to the shape and the setting of a certain angle of attack. This action produces a force on the shaft and a torque on the blade. The complete system is mounted on a buoyant decks pontoon in rivers or flowing streams of water.

In the present review study general introduction to water current turbines; literature review; theories of aerofoils, which include aerofoils definitions, aerofoils terminologies, geometrical parameters of aerofoils, aerofoils types; generation of lift and drag; and conclusions were presented and discussed thoroughly.

REFERENCES

[1] Garman P., ‘Water Current turbines’, a field worker’s guide, II publications, London, 1986.
[2] Blue energy Canada, http://www.blueenergy.com, accessed 6 March 1999, 30 Sept. 2002.
[3] Hilton D. J., ‘A vertical axis water turbine for extracting energy from rivers and tidal currents’, proceedings of the 1st international conference on technology for development, I E Aust/ ADAB et al, Canberra, 24-28 November 1980, pp. (138-141).
[4] Baker A. C., ‘Tidal power, Peter Peregrinus Ltd, 1991.
[5] Pearce F., ‘Catching the tide’, new scientist, 20 June 1998, pp. (34-41).
[6] Fraenkel P. L., Cultterbuck P., Stjernstrow B. and Bard J. ‘Sea How’, preparing for the world’s first pilot project for the exploitation of marine currents at a commercial scale, proceedings of the 3rd European wave energy conference, Patras, Sept - Oct. 1998.
[7] Fraenkel P. L., ‘Tidal currents’, a major new source of power for the millennium, sustainable development international No. 1, 1999, PP. (107-112), ICG publishing, http://www.sustdev.org.
[8] Fraenkel P. L., ‘Marine Currents’, a promising large clean energy source, proceedings of the international mechanical engineering conference, ‘power generation by renewables’, London, 15-16 May, 2000.
[9] Fraenkel P.L., ‘power from marine currents’, proceedings of the Inst. Mech. Eng., J. power and energy 216(A1), 2002, PP.(1-14).
[10] Cairo D., Department of Aeronautical Engineering, University of Naples, Pers. Comm, 2001, 2003.
[11] Zoeb Husain, Zulkifly Abdullah, Zainal Alimuddin, ‘Basic fluid mechanics and hydraulic machines, BS publications, Hyderabad, 2008.
[12] Rama S.R. Gorla, Aijaz A. khan, ‘Turbo machinery design and theory’, Marcel Dekker, Switzerland, 2003.
[13] Bernard Massey, ‘Mechanics of fluids’, Taylor and Francis, USA, sixth edition, 2006.
[14] Bernard Massey, ‘Mechanics of fluids-solution manual, Taylor and Francis, USA, eighth edition, 2006.
[15] John F. Douglas, Janusz M. Gasiork, John A. Swaffield, Lynne B. Jack ‘Fluid mechanics’, sixth edition, Pearson publishers.

[16] John F. Douglas, ‘solving problems in fluid mechanics, vol. 2’, prentice Hall, 1996.
[17] John F. Douglas, ‘solving problems in fluid mechanics, vol. 1’, prentice Hall, 1996.
[18] Kari Sornes, ‘small scale water current turbines for river applications’, January 2010, zero emission resource organization.
[19] Thropton energy, physic lane, Thropton, North umber land NE65 7HV, United Kingdom, January 2010, http://www.throptonenergy.co.uk.
[20] Alternative energy, January 2010, http://www.alternativeenergy-news.info/
[21] S. Gahin, Mustafa M. Elsayed, Mohammed A. Ghazi, ‘Introduction to engineering mechanics’, King Abdul-Aziz University, Jeddah, Saudi Arabia, 1985.
[22] Bachelor, G. K., ‘An introduction to fluid dynamics, Cambridge University press, 1967.
[23] Duncan, W. J. A. S. Thom, and A. D. Young, ‘Mechanics of fluids’, the Gresham press, Edward Arnold limited, 1978.
[24] Fox, R. W., and A. T. McDonald, ‘Introduction to fluid mechanics’, John Wiley and Sons, 1978.
[25] Hughes, W. F. and J. A. Brighton, ‘Fluid dynamics Schaum's outline series’, McGraw – Hill Book Company, 1967.
[26] James E. A. John, William L. Haberman, ‘Introduction to fluid mechanics’, Prentice Hall, Inc. 1980.
[27] Massey, B. S., ‘Mechanics of fluids dynamics’, Van Nostrand company Ltd, 1968.
[28] Kay, J. M. and R. M. Nedderman, ‘An introduction to fluid mechanics and heat transfer’, Cambridge University press, 1977.
[29] Schlichting, H., ‘Boundary – Layer theory’, McGraw – Hill, 1968.
[30] Webber, N. B., ‘Fluid mechanics for civil engineers’, University of Southampton, 1968.
[31] Streeter, V. L., and E. B. Wylie, ‘Fluid mechanics, McGraw – Hill Book Company, 1975.
[32] Stephen J. Kline, ‘Similitude and approximation theory’, McGraw – Hill Book Company, 1965.
[33] Osama Mohammed Elmardi Suleiman, (2015). Further Experimental Research Work on Water Current Turbines, LAP LAMBERT Academic Publishing, Member of Omni Scriptum Publishing Group, Germany, ISBN: 978-3-659-58160-1.
[34] Osama Mohammed Elmardi Suleiman Khayal & Mahmoud Yassin Osman, July (2018). Atbara Water Current Turbine, International Journal of Engineering & Computer Science (IJECS), Vol. 1 No. 1, PP. 30 – 46.