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Optimization of the energy potential of sewage networks.

Biskra case

Forename and Surname of the student:
Mohamed Lamine HIMER

Supervisor:
Pr. Mohamed Toufik BOUZIANE

Co-supervisor:
Dr. Yazid LOUGHRAICHI

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Dedication

I dedicate my dissertation work to my family. A special Feeling of gratitude to my loving parents, which has provided me with their encouragement, Love and understanding.

To all my extended family, big and small, To all my friends and colleagues.

To all the staff of the civil and hydraulic engineering department

To all the teachers who contributed to my training.

ABSTRACT

One of the most efficient ways to generate electric energy is hydropower, as humans started using the energy stored in water thousands of years ago, currently the energy problem is considered one of the most important problems that people will face in the future.
And engineers have found at the present time a lot of ways to benefit as much as possible from this energy, so that we will in this research study methods of generating electric energy using wastewater energy. The principle is simple: it depends on passing water on the turbines either at the entrance to the treatment plant, when it is located downstream, or when it is discharged into a pipeline under pressure.
In this research, we will study a turbine model for the discharge of wastewater from the city of Biskra using numerical simulation models. and also we will try to find the most appropriate design (pipe diameters, turbine diameter, manufacturing materials ...) in order to obtain the best yield.

Key words: Wastewater, Sewage network, Turbine, Hydropower, Model, Simulation.

ملخص

واحدة من أكثر الطرق كفائة لتوليد الطاقة الكهربائية هي الطاقة المائية، حيث بدأ الإنسان باستخدام الطاقة المختزنة بالمياه منذ آلاف السنين، حاليا تعتبر مشكلة الطاقة من أهم المشاكل التي ستواجه الإنسان في المستقبل.
و قد توصل المهندسين في الوقت الحالي إلى الكثير من الطرق لأجل الإستفادة قدر الإمكان من هذه الطاقة، بحيث سنقوم في هذا البحث بدراسة طرق توليد الطاقة الكهربائية باستعمال طاقة مياه الصرف الصحي. المبدأ بسيط: فهو يعتمد على تمرير المياه على توربينات إما عند مدخل محطة المعالجة ، أو عندما تكون موجودة أسفل المصب، أو عند تصريفها في خط أنابيب تحت الضغط.
و في هذا البحث سنقوم بدراسة نمودج توربين لمصب المياه المستعملة لبلدية بسكرة باستعمال المحاكاة في الحاسوب.
و كذلك سوف نحاول إيجاد التصميم الأنسب من (أقطار الأنابيب، قطر التوربين، مواد التصنيع...) لأجل الحصول على أفضل مردود.

كلمات مفتاحية : االمياه المستعملة ، شبكة الصرف الصحي ، التوربينات ، الطاقة الكهرومائية ، النموذج ، المحاكاة .

RÉSUMÉ

L'hydroélectricité est l'une des méthodes les plus efficaces pour produire de l'énergie électrique, car les humains ont commencé à utiliser l'énergie stockée dans l'eau il y a des milliers d'années. Actuellement, le problème énergétique est considéré comme l'un des problèmes les plus importants auxquels les gens seront confrontés à l'avenir.
Et les ingénieurs ont trouvé de nombreuses façons actuellement de tirer le meilleur parti de cette énergie, afin que nous étudions dans cette recherche les méthodes de génération d'énergie électrique en utilisant l'énergie des eaux usées. Le principe est simple: il repose sur le passage de l'eau sur les turbines soit à l'entrée de la station d'épuration, lorsqu'il est situé en contrebas de l'estuaire, soit lorsqu'il est déversé dans une canalisation sous pression.
Dans cette recherche, nous étudierons un modèle de turbine pour le rejet des eaux usées de la ville de Biskra en utilisant des modèles de simulations numérique. et aussi nous essaierons de trouver la conception la plus appropriée (diamètres de tuyauterie, diamètre de turbine, matériaux de fabrication ...) afin d'obtenir le meilleur rendement.

Mots clés: Eaux usées, réseau d'égouts, turbines, énergie hydroélectrique, modèle, simulation.

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GENERAL INTRODUCTION

OWING to increasing demand in clean energy and rising fossil fuel prices, more and more investment and research are focused on the renewable energy resources. These include energy that has been derived from earth's natural resources that are not finite or exhaustible, such as: wind, sunlight and hydropower in the most cases .(Wang et al., 2007)

On a global scale, there is a great unused renewable hydropower, especially in small water resources. often hydropower energy facilities are constructed in order to reduce the overall demand of energy supply taken from the power grid. Small hydropower solutions in combined sewer systems may be part of this strategy (Frehmann et al., 2013). Fortunately, most wastewater treatment facilities can significantly reduce their energy costs, by up to 30% or more, through energy efficiency measures and treatment process modifications. Through optimized aeration and improved pumping systems and energy recovery by wastewater turbining (Stillwell et al., 2010) .

These energy recovery strategies could help offset the electricity consumption of the wastewater sector and represent possible areas for sustainable energy policy implementation. Our analysis considers energy consumption and potential savings only; the economics of energy recovery from wastewater treatment, while highly relevant, is reserved for a separate analysis.

This work gives an overview of the approaches attempted, suitable techniques, and restrictions and boundary conditions which have to be considered for an operation of small hydropower concepts in urban drainage systems of the city of Biskra.

This work is divided into four chapters which are organized as follows:

- The first chapter divided into two main part: the first part explains generalities about hydroelectric energy, its importance and methods of exploitation, in addition to the various parts of hydroelectric power plan. The second part deals with turbine machinery in terms of their types and characteristics, how to choose the proper type in addition to how to calculate all the related features.

- The second chapter we will talk about the electric power generation systems from sewage networks, and how to enter economics accounts in choosing the type and placement of the system. In addition to examples around the world of stations that use this technology.

- The third chapter deals with general information about the outfall of Biskra city sewage network ,as well as estimating the electric energy that we will produced, In addition to choosing the proper type of turbine and determining the dimensions of its structures. We will also talk about how to choose the materials suitable for the manufacture of turbine and its materials in order to resist various chemical factors of water.

- The last chapter explains the various engineering calculations used in the design of the Kaplan turbine model used in the downstream of the sewage network for the city of Biskra, where we will perform a CFD-simulation of the the model using the Ansys-CFX program, where we will calculate the various variables in the turbine work from electrical energy, the yield, the pressures applied to Turbine ... and all this in order to obtain the best possible yield and to reduce losses.

Our study ends with a general conclusion or are synthesized the results as well obtained.

CHAPTER 1

GENERALITIES ABOUT HYDRAULIC TURBINES AND HYDROELECTRIC POWER PLAN

1.1 Introduction

TURBINE machinery is a subject of great importance today. People's life is greatly influenced by use of electric energy. Extensive use of electric energy has dramatically changed everyone's life. We are almost unable to imagine life without use of electric motors, domestic appliances and consumer electronics. Clothes washing and drying machines, refrigerators, microwave ovens, television sets, audio and video electronics, air conditioning and computers fall in this category. Almost all the available electric energy nowadays is produced with the use of turbine machinery. Turbine machinery is also used for aero and naval propulsion and in internal combustion engines featuring turbochargers.

1.2 General overview of hydropower schemes

Hydropower can be generated wherever a flow of water descends from a higher level to a lower level. The difference between the two water surface elevations is referred to as head. Head can exist in nature, for instance when a stream runs down a steep hillside or when a sharp change in elevation creates a waterfall in a river. However, head can also be created artificially by constructing a weir or dam; the dam creates a

barrier to water flow, raising the upstream water level to the desired elevation.
As a result of elevation differences gravitational potential energy is stored in the water; this energy can be exploited by installing turbines and generators. Water flow moves the turbine blades, thereby converting water's potential energy into kinetic energy. The turbine rotation forces the generator rotator to spin around the stator thereby converting kinetic energy first to mechanical energy, and then to electrical energy.(International finance corporation, nd)

1.3 Components and cross section of a small hydroelectric power plant

1.3.1 The components

(i) **Water source:** Because the source of hydroelectric power is water, hydroelectric power plants are usually located on or near a water source. In a storage system, water accumulates in reservoirs created by dams and is released as needed to generate electricity.

(ii) **Pipeline:** is a hydraulic pipe, that is to say an assembly of pipes, transporting pressurized water to a hydroelectric plant located downstream and below the reservoir which supplies it.
Depending on the topographic conditions and the technological possibilities at the time of their construction, Pipeline can be overhead or underground, made of various materials such as steel, reinforced or pre stressed concrete ...

(iii) **Head of water:** is the change in water levels between the hydro intake and the hydro discharge point. It is a vertical height measured in metres. ... The more head you have the higher the water pressure across the hydro turbine and the more power it will generate.

(iv) **Water turbine:** A water turbine is a rotary machine that converts kinetic energy and potential energy of water into mechanical work. Water turbines were developed in the 19th century and were widely used for industrial power prior to electrical grids. Now they are mostly used for electric power generation.

(v) **Generator**: a machine that converts one form of energy into another, especially mechanical energy into electrical energy, as a dynamo.

(vi) **Transformer:** An electrical transformer is an electrical machine making it possible to modify the values of voltage and current intensity delivered by an alternative source of electrical energy, into a system of voltage and current of different values, but of the same frequency and the same shape . It performs this transformation with excellent yield.
the transformer has made the long-distance transmission of electric power.

(vii) **Control valve:** It is a flow control organ.

(viii) **Trailrace:** a race for conveying water away from a point of industrial application (such as a waterwheel or turbine) after use (VISUAL DICTIONARY, nd).

1.3.2 The cross section

Most hydroelectric power plants contain the following components, (All the components are detailed in the previous title):

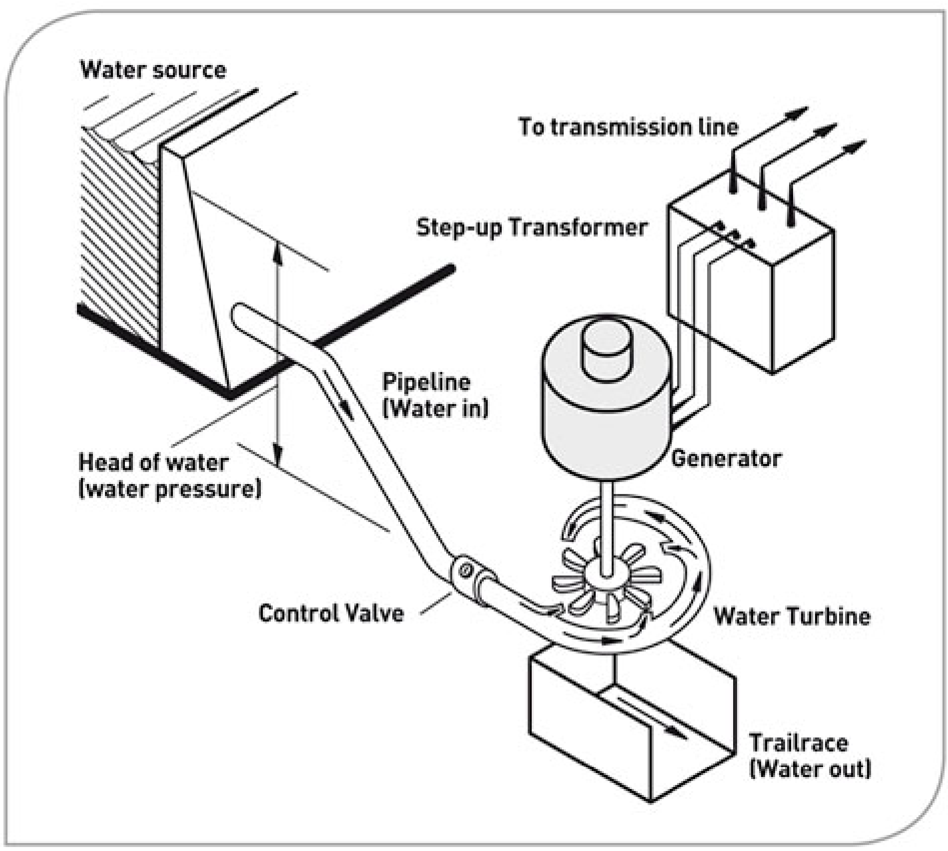


Figure 1.1: Scheme of a micro hydro power plant(Veolia, nd)

1.4 Classification of turbines

The main classification depends upon the type of action of the water on the turbine. These are : *Impulse turbine* and *Reaction turbine*. In the case of impulse turbine all the potential energy is converted to kinetic energy in the nozzles. The impulse provided by the jets is used to turn the turbine wheel. The pressure inside the turbine is atmospheric. This type is found suitable when the available potential energy is high and the flow available is comparatively low. Some people call this type as tangential flow units. Later discussion will show under what conditions this type is chosen for operation.

In reaction turbines the available potential energy is progressively converted in the turbines rotors and the reaction of the accelerating water causes the turning of the wheel. These are again divided into radial flow, mixed flow and axial flow machines. Radial flow machines are found suitable for moderate levels of potential energy and medium quantities of flow. The axial machines are suitable for low levels of potential energy and large flow rates. The potential energy available is generally denoted as "head available". With this terminology plants are designated as "high head", "medium head" and "low head" plants.(Kothandaraman & Rudramoorthy, 2007)

1.4.1 Impulse turbine

1.4.1.1 Pelton turbine

The Pelton turbine was performed in high head and low water flow, in establishment of micro-hydro electric power plant, due to its simple construction and ease of manufacturing.. This type of turbine was developed and patented by L.A. Pelton in 1889 and all the type of turbines are called by his name to honour him. (Nasir, 2013)

The Pelton turbine is an impulse turbine where all the energy is converted to kinetic energy in front of the runner. There is then no pressure drop from the inlet to the outlet of the runner.(Brekke, 2001)

A sectional view of a horizontal axis Pelton turbine is shown in figure (1.2) The main components are (1) The runner with the (vanes) buckets fixed on the periphery of the same. (2) The nozzle assembly with control spear and deflector (3) Brake nozzle and (4) The casing.

The number of jets is obtained by dividing the total rate of flow through the turbine by the rate of flow of water through a single jet.

In general, Number of jets are limited to two in case of vertical runner and six in case of horizontal runner.

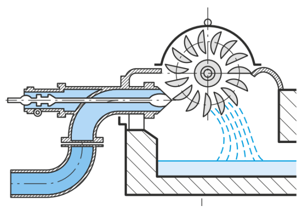


Figure 1.2: Cross section of a Pelton turbine (Techniques de l'ingénieur, nd)

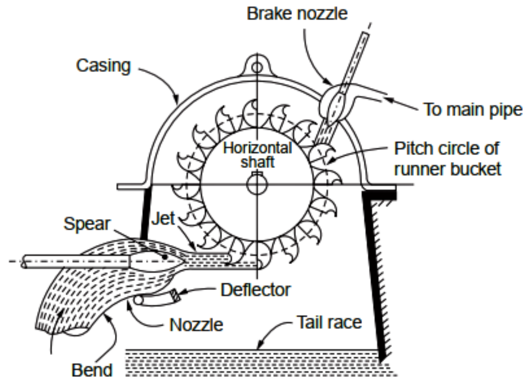


Figure 1.3: Main component of Pelton turbine.(Kothandaraman & Rudramoorthy, 2007)

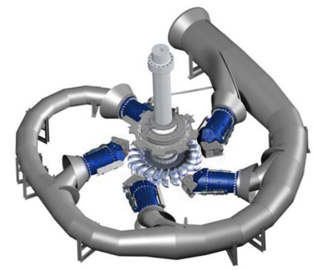


Figure 1.4: Example of a multi-jet Pelton turbine (Manno, 2013)

1.4.1.2 Cross flow turbine

The Cross flow turbine (also called Banki turbine) is suitable for flow rates from 20 to 1000 l/s and falls from 2 to 200 meters. It is also called a flow-through turbine because water crosses twice the wheel.
The cross-flow turbine allows the water to flow through the blades twice. The first pass is when the water flows from the outside of the blades to the inside; the second pass is from the inside back out. A guide vane at the entrance to the turbine directs the flow to a limited portion of the runner. The cross-flow was developed to accommodate larger water flows and lower heads than the Pelton It can be divided into three main parts (Popescu et al., 2017):

⊛ An injector whose flow rate is adjusted using a rotary vane. In order to ensure a stop of the turbine without additional energy, closing is often carried out using a counterweight and opening by a hydraulic cylinder.

⊛ A drum-shaped wheel with profiled cylindrical blades.

⊛ A frame surrounding the wheel on which the turbine bearings are fixed.

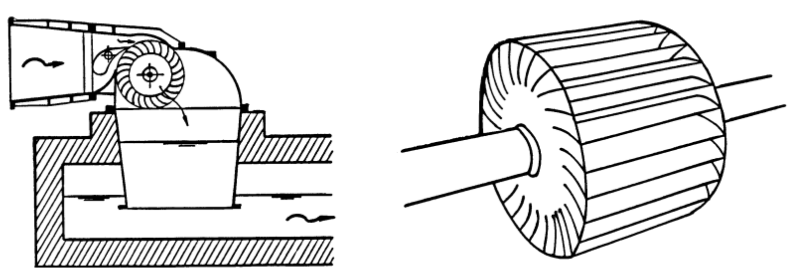


Figure 1.5: Cross flow turbine (PACER, 1995)

1.4.2 Reaction turbine

1.4.2.1 Francis turbine

This turbine is the most widespread. It allows the valuation of low or medium falls height (from 60 to 300 meters) and can develop a very significant power. Its diameter varies from 0.6 to 8 meters. It consists of a spiral pipe (spiral tarpaulin) which leads the water to a dispenser. The distributor consists of a series of guidelines (blades) which guide the water towards the wheel. The turbine wheel is placed inside the distributors.

The main components are (1) The spiral casing (2) Guide vanes (3) Runner (4) Draft tube and (5) Governor mechanism. Most of the machines are of vertical shaft arrangement while some smaller units are of horizontal shaft type.(Brekke, 2013)

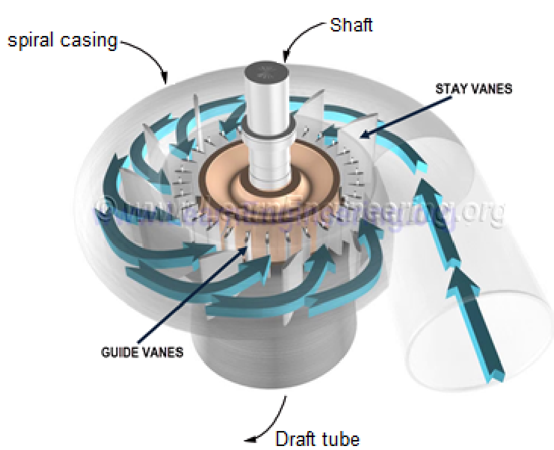


Figure 1.6: Francis turbine (FLUID MECHANICS, 2016)

Figure 1.7: CAD Model Francis Runner. (RevEng, n d)

1.4.2.2 Kaplan turbine

The popular axial flow turbines are the Kaplan turbine and propeller turbine. Kaplan and propeller turbines are used for small falls (from 15 to 30m). The corresponding powers can vary from a few kW to several hundred kW. These are turbines that are found over the water and which therefore have no tank, their diameter varies from 1 to 11 meters. In general the propeller turbines are found in great number These turbines are characterized by a propeller-shaped wheel with blades can be adjustable on the fly (in the case of a Kaplan).

In the Kaplan turbines the blades are mounted in the boss in bearings and the blades are rotated according to the flow conditions by a servomechanism maintaining constant speed. In this way a constant efficiency is achieved in these turbines.(Kothandaraman & Rudramoorthy, 2007)

We classify them according to the type flow:

- ▷ constant flow: a propeller turbine with fixed blades and distributor.
- ▷ high and not very variable flows: a propeller turbine with fixed blades and a distributor mobile.
- ▷ Dash Variable flows between 30 and 100% of the nominal flow: a Kaplan turbine with distributor fixed.
- ▷ Dash Variable flows between 15 and 100% of the nominal flow: a Kaplan turbine with distributor adjustable. It is the most complicated because it has two regulatory possibilities which must be tuned together for the best results.

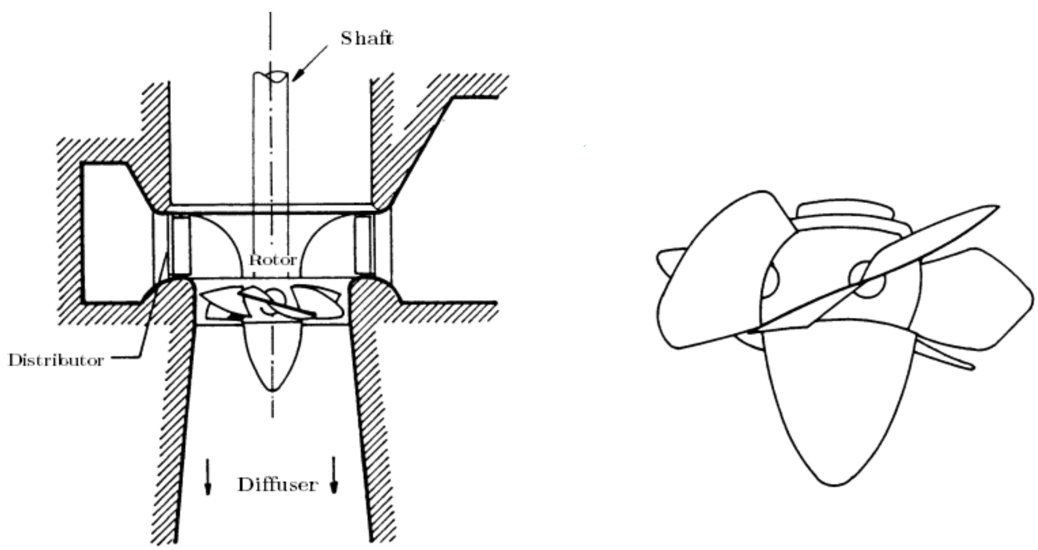


Figure 1.8: Kaplan turbine (PACER, 1995)

1.5 Characteristics of water turbines

1.5.1 Conditions for choosing the type of turbine

The objective of this step is to achieve the sizing of the most suitable machine meeting the data of the site to be equipped: net height H, available volume flow Q. The most suitable machine most often means the one which will present the best performance for a rotation speed "N" mechanically acceptable and which, in the second place, will present the better adaptability to the site.

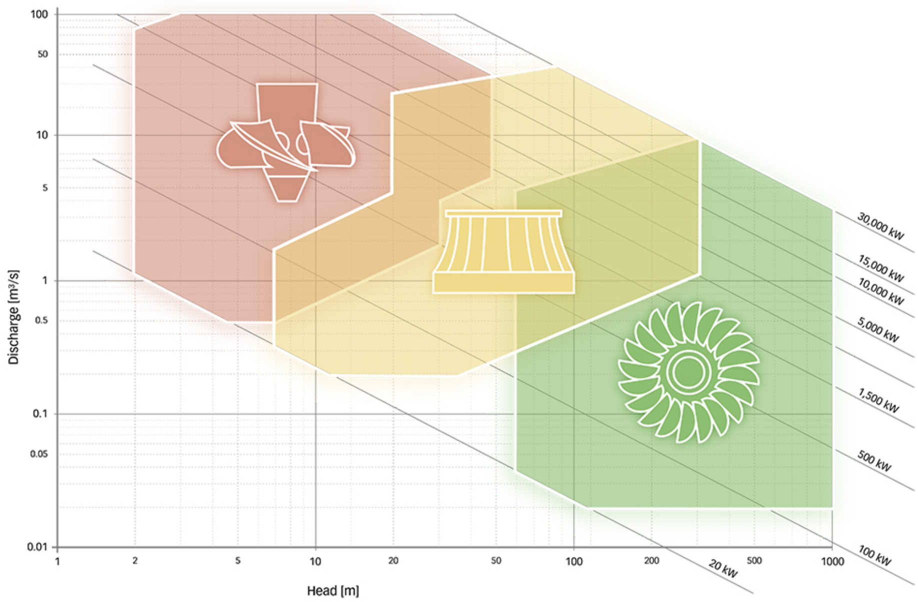


Figure 1.9: Types of hydraulic turbine by application area (ANDRITZ, nd)

1.5.2 The specific speed

The specific speed N_q is the most important characteristic for water turbines. It is the speed of a geometrically similar turbine which would produce unit power (one kilowatt) under unit head (one meter). The specific speed of a turbine is given by the manufacturer (along with other ratings) and will always refer to the point of maximum efficiency. and we have

$$N_{sp} = \frac{NQ^{1/2}}{H^{3/4}} \tag{1.1}$$

Here, N is the rotational speed in (rpm), Q the flow rate in (m^3/s) and (H) the head of the water turbine in (m).

Table 1.1: the type of turbine according to the specific speed(Kothandaraman & Rudramoorthy, 2007)

specific speed	Type of turbine
8-29	Single jet Pelton turbine
26-40	Twin jet Pelton turbine
40-67	Multiple jet Pelton turbine
67-450	Radial flow turbine Francis type (H < 350m)
364-910	Axial flow Kaplan turbine. (H < 60m)

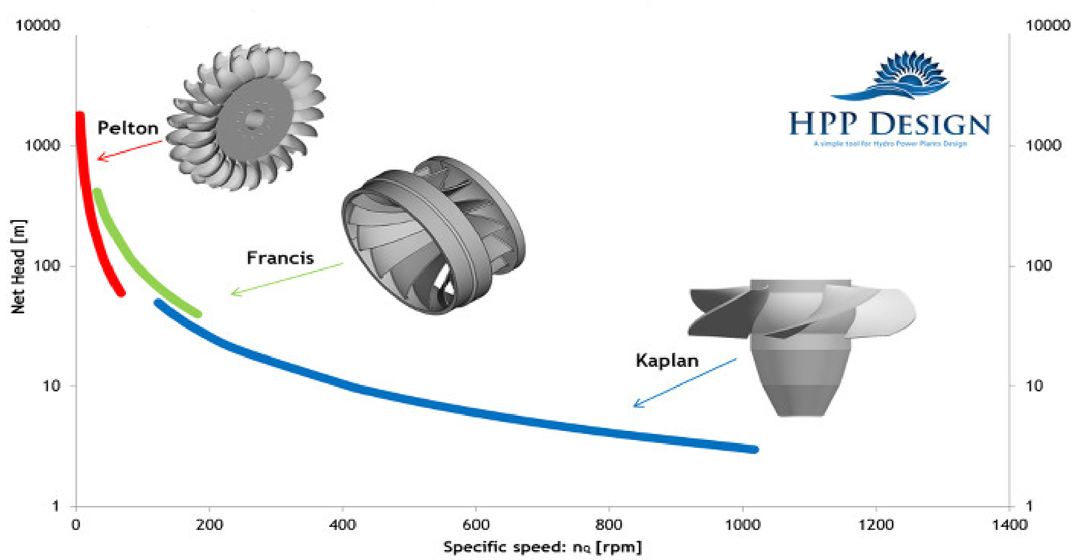


Figure 1.10: the turbine specific speed (Santonil, 2016)

1.5.3 The significance of specific speed

Specific speed does not indicate the speed of the machine. It can be considered to indicate the flow area and shape of the runner. When the head is large, the velocity when potential energy is converted to kinetic energy will be high. The flow area required will be just the nozzle diameter. This cannot be arranged in a fully flowing type of turbine. Hence the best suited will be the impulse turbine. When the flow increases, still the area required will be unsuitable for a reaction turbine. So multi jet unit is chosen in such a case. As the head reduces and flow increases purely radial flow reaction turbines of smaller diameter can be chosen. As the head decreases still further and the flow increases, wider rotors with mixed flow are found suitable. The diameter can be reduced further and the speed increased up to the limit set by mechanical design. As the head drops further for the same power, the flow rate has to be higher. Hence axial flow units are found suitable in this situation. Keeping the power constant, the specific speed increases with N and decreases with head. The speed variation is not as high as the head variation. Hence specific speed value increases with the drop in available head. This can be easily seen from the values listed in table 1.1 .

1.5.4 Hydraulic power of a turbine

Hydraulic power is the power supplied to the turbine by the water that feeds it.
It is given by the product of hydraulic energy with the mass flow (volume flow per specific mass). hydraulic power is already calculable by the classical formulation (PACER, 1995):

$$P_{hyd} = \rho g Q H \tag{1.2}$$

with:
P_{hyd} : Hydraulic power in (W).
Flow (Q): Discharge passing through the turbine in (m^3/s).
Head (H): Net head between the upper and the lower water level in meter (m).
g : acceleration due to gravity ($g = 9{,}81$ (KN/m^3)).

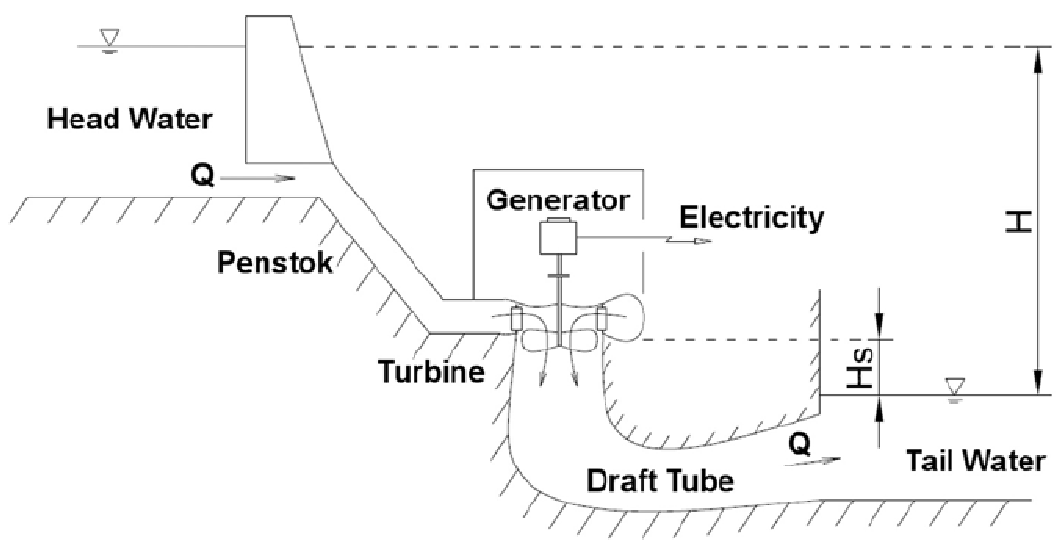


Figure 1.11: Hydraulic turbine installation diagram with its different parts and variables. (Stefan et al., 2012)

1.5.5 Torque, rotation speed, mechanical power and efficiency of a turbine

1.5.5.1 Torque

symbol: (T); Unit: $(N.m)$

The pressurized water entering the turbine exerts a hydrodynamic force on the impeller blades or buckets. This force creates a torque which puts the wheel in rotation.

1.5.5.2 rotational speed

Symbol: (N); Unit: (rpm) or (rad/s); with: $\omega = 2\pi N/60 = \pi N/30$ (rad/s)

Once set in motion, the turbine will rotate at a speed of rotation determined by the operating conditions.

1.5.5.3 Mechanical power or to the turbine shaft

Symbol: P_{mec}; Unit: W

By the laws of physics, mechanical power is given by the product of the torque by the speed of rotation:

$$P_{mec} = \omega T \tag{1.3}$$

1.5.5.4 efficiency

Symbol: η

The head available for hydroelectric plant depends on the site conditions. Gross head is defined as the difference in level between the reservoir water level (called head race) and the level of water in the stream into which the water is let out (called tail race), both levels to be observed at the same time. During the conveyance of water there are losses involved. The difference between the gross head and head loss is called the net head or effective head. It can be measured by the difference in pressure between the turbine entry and tailrace level. The following efficiencies are generally used(Kothandaraman & Rudramoorthy, 2007).

There are many kinds of hydraulic efficiency :

Hydraulic efficiency : It is defined as the ratio of the power produced by the turbine runner and the power supplied by the water at the turbine inlet. (Kothandaraman & Rudramoorthy, 2007)

$$\eta_h = \frac{\text{Power produced by the runner}}{\rho g H Q} = \frac{\text{Power produced by the runner}}{P_{hyd}} \tag{1.4}$$

where Q is the volume flow rate and H is the net or effective head. Power produced by the runner is calculated by the Euler turbine equation $P = Q\rho[u_1 V_{u1} - u_2 V_{u2}]$. This reflects the runner design effectiveness.(Kothandaraman & Rudramoorthy, 2007)

Volumetric efficiency : It is possible some water flows out through the clearance between the runner and casing without passing through the runner.
Volumetric efficiency is defined as the ratio between the volume of water flowing through the runner and the total volume of water supplied to the turbine. Indicating Q as the volume flow and ΔQ as the volume of water passing out without flowing through the runner.(Kothandaraman & Rudramoorthy, 2007)

$$\eta_v = \frac{Q - \Delta Q}{Q} \tag{1.5}$$

To some extent this depends on manufacturing tolerances.

Mechanical efficiency : The power produced by the runner is always greater than the power available at the turbine shaft. This is due to mechanical losses at the bearings, windage losses and other frictional losses.(Kothandaraman & Rudramoorthy, 2007)

$$\eta_m = \frac{\text{Power available at the turbine shaft}}{\text{Power produced by the runner}} \tag{1.6}$$

Overall efficiency : This is the ratio of power output at the shaft and power input by the water at the turbine inlet.(Kothandaraman & Rudramoorthy, 2007)

$$\eta_o = \frac{\text{Power available at the turbine shaft}}{\rho Q g H} \tag{1.7}$$

Also the overall efficiency is the product of the other three efficiencies defined (Kothandaraman & Rudramoorthy, 2007)

$$\eta_o = \eta_h \eta_m \eta_v \tag{1.8}$$

1.5.6 Efficiency characteristic curves of a turbine

In order to be able to predict the behaviour of a turbine for the different operating conditions, the manufacturers establish, using model tests, the characteristic curves valid for a turbine of given shapes. The characteristic curves of a turbine model are measured on a test bench, at the manufacturer or in a specialized laboratory.
When the manufacturer makes a full-scale machine, which will be identical in shape to the model, the operating curves, or characteristic curves, from the latter are converted for the turbine manufactured using the laws of similarity.(PACER, 1995)

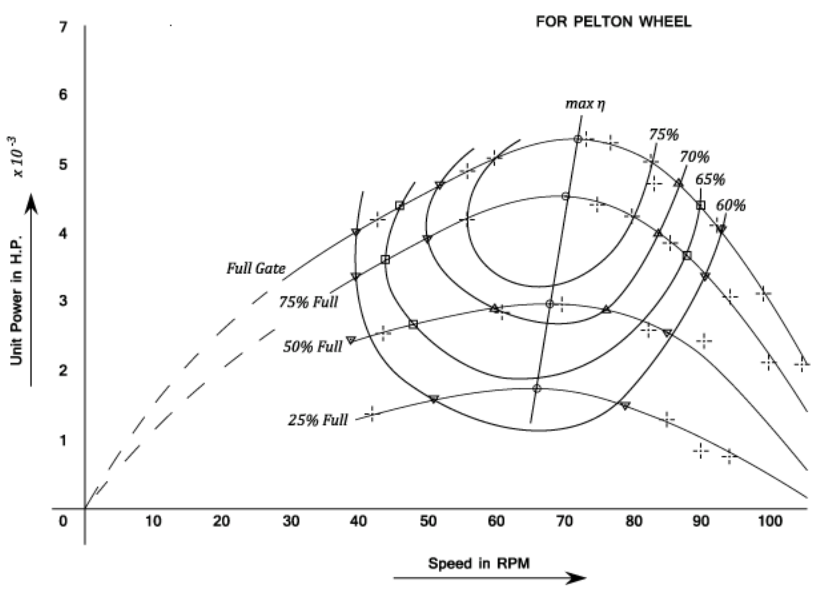


Figure 1.12: Example of characteristic curve of a turbine (CODECOGS, nd)

1.6 Similitude and model testing

1.6.1 Model and Prototype

It is found not desirable to rely completely on design calculations before manufacturing a large turbine unit. It is necessary to obtain test results which will indicate the performance of the large unit. This is done by testing a "homologous" or similar model of smaller size and predicting from the results the performance of large unit. Similarity conditions are three fold namely geometric similarity, kinematic similarity and dynamic similarity. Equal ratios of geometric dimensions leads to geometric similarity.

1.6.2 Tests on scale models

To be able to predict the behaviour of a turbine for the various operating conditions, the manufacturers establish, using model tests, the characteristic curves valid for a turbine of given shapes.

The characteristic curves of a turbine model are measured on a test bench, at the manufacturer or in a specialized laboratory (engineering school or university).

When the manufacturer makes a full-scale machine, which will be identical in shape to the model, the operating curves, or characteristic curves, from the latter are converted for the turbine manufactured using the laws of similarity.(PACER, 1995)

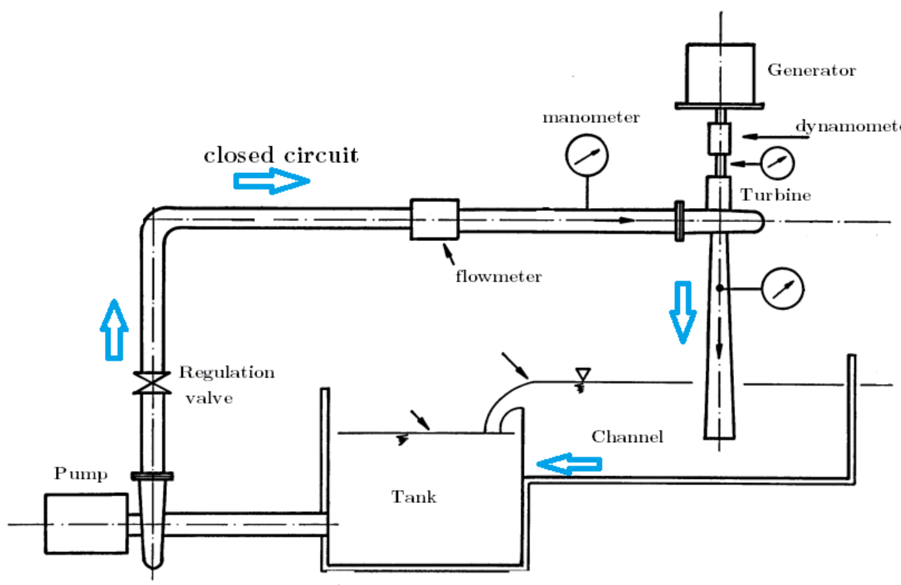


Figure 1.13: Schematic diagram of a test bench for hydraulic turbine models (PACER, 1995)

1.6.3 Unit Quantities

The dimensionless constants can also be used to predict the performance of a given machine under different operating conditions. As the linear dimension will be the same, the same will not be taken into account in the calculation. Thus (Kothandaraman & Rudramoorthy, 2007)

Head coefficient will now be:

$$\frac{H_1}{N_1^2 D^2} = \frac{H_2}{N_2^2 D^2} \; or \; \frac{H_2}{H_1} = \frac{N_2^2}{N_1^2} \tag{1.9}$$

The head will vary as the square of the speed.

The flow coefficient will lead to:

$$\frac{Q_1}{N_1 D^3} = \frac{Q_2}{N_2 D^3} \text{ or } \frac{Q_2}{Q_1} = \frac{N_2}{N_1} \tag{1.10}$$

Flow will be proportional to N and using the previous relation

$$\frac{Q_2}{Q_1} = \sqrt{\frac{H_2}{H_1}} \; or \frac{Q}{\sqrt{H}} = \text{ constant for a machine} \tag{1.11}$$

The constant is called unit discharge.

$$\text{Similarly } \frac{N_2}{N_1} = \sqrt{\frac{H_2}{H_1}} \text{ or } \frac{N}{\sqrt{H}} = \text{constant} \tag{1.12}$$

This constant is called unit speed.

Using the power coefficient :

$$\frac{P_1}{N_1^3 D^5} = \frac{P_2}{N_2^3 D^5} \text{ or } \frac{P_2}{P_1} = \frac{N_2^3}{N_1^3} = \left(\frac{H_2}{H^1}\right)^{3/2} \tag{1.13}$$

Hence when H is varied in a machine the other quantities can be predicted by the use of unit quantities.

1.6.4 Change of characteristics of a given turbine

A turbine of known dimensions works under a fall variable with a given geometric opening. Relationships between the different parameters are as follows:

Table 1.2: Laws of Similarity (PACER, 1995)

Fall (m)	H_1	H_2
Flow (m^3/s)	Q_1	$Q_2 = Q_1\sqrt{\frac{H_2}{H_1}}$
Rotational speed (rpm)	N_1	$N_2 = N_1\sqrt{\frac{H_2}{H_1}}$
Torque (Nm)	T_1	$T_2 = T_1\frac{H_2}{H_1}$
Power $(W \text{ or } KW)$	P_1	$P_2 = P_1\frac{H_2^{3/2}}{H_1^{3/2}}$

Using these formulas, it is possible to calculate the new characteristics of a turbine built for a given site and moved to another, different fall. This can happen when buying a used turbine.

1.7 Cavitation in hydraulic turbines

oil at that point and bubbles of vapour will form. As the fluid flows into a region of higher pressure the bubbles of vapour will suddenly condense or collapse. This action produces very high dynamic pressure upon the adjacent solid walls and since the action is continuous and has a high frequency the material in that zone will be damaged. Turbine runners and pump impellers are often severely damaged by such action. The process is called cavitation and the damage is called cavitation damage. In order to avoid cavitation, the absolute pressure at all points should be above the vapour pressure.
n the case of reaction turbines at the turbine exit or draft tube inlet where the pressure may be below atmospheric level.
In addition to the damage to the runner cavitation results in undesirable vibration noise and loss of efficiency. The flow will be disturbed from the design conditions. In reaction turbines the most likely place for cavitation damage is the back sides of the runner blades near their trailing edge. The critical factor in the installation of reaction turbines is the vertical distance from the runner to the tailrace level. For high specific speed propeller units it may be desirable to place the runner at a level lower than the tailrace level.

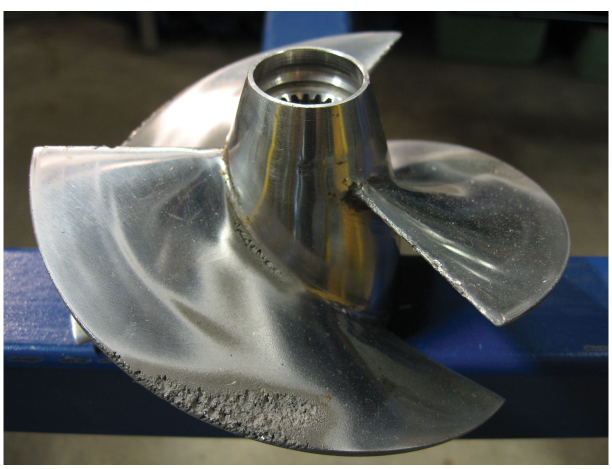


Figure 1.14: Pitted surface of a boat propeller due to cavitation. (The Editors of Encyclopaedia Britannica, 2020)

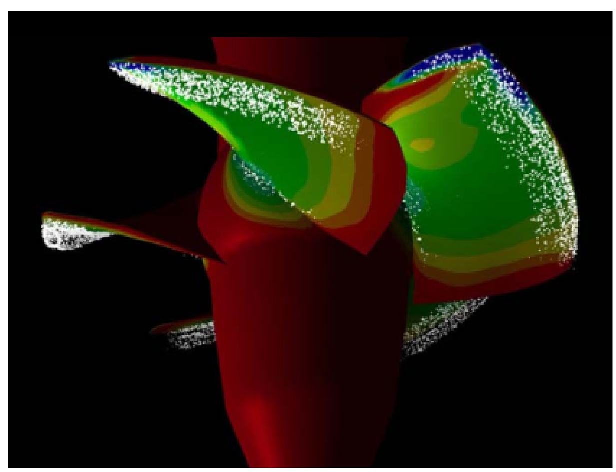


Figure 1.15: Simulation of cavitation bubbles near Kaplan runner blades. (Kumar & Saini, 2010)

CHAPTER 2

WASTEWATER TURBINATION SYSTEMS

2.1 Introduction

GREAT efforts have long been exerted in harnessing renewable energy in a simultaneous response to both the energy crisis and environmental pollution. Sewage networks are a sustainable model for recovering energy stored in water in the form of usable electric energy by the use of hydraulic turbines, The principle is simple: it involves turbinating the water either at the entrance to the treatment plant, when it is located below the agglomeration, or when discharged into a pipeline or a river when it is aloft.(Chenal et al., 1995)

2.2 Wastewater turbining systems

There are several possibilities for hydroelectric production on the sewage networks:

- Turbine wastewater before they are not processed at the wastewater treatment plan (WWTP) in (Figure 2.1).

  In this case, the sewerage network of a built-up area, located at an altitude, results in a sifting and charging chamber. The used water is then brought by a penstock to the purification plant, located in the valley, where it is turbinated before being treated.

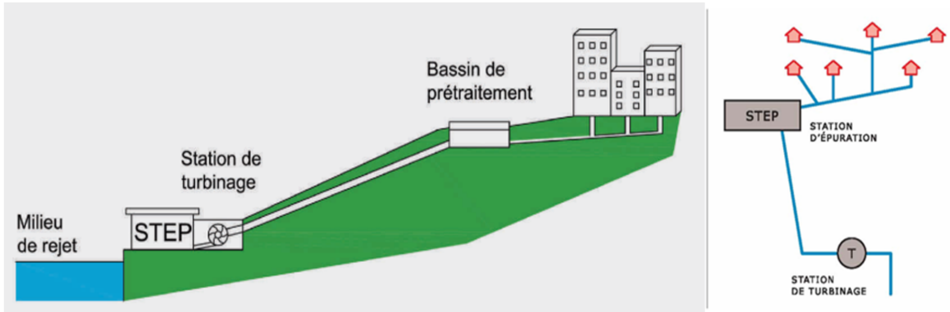


Figure 2.1: Turbination before treatment (MHylab, 2008)

▷ Turbine the treated waste water before their rejection in a natural environment (Figure 2.2).
In this case, the (WWTP) is located at an altitude, and it is the purified water which descended into the valley by a penstock to end up with a turbine installation, before being discharged into a lake or a course. water. This method will mainly be used when the watercourse in which the discharge is to be made (at altitude) is at too low a flow and the dilution is not sufficient, or when there is no watercourse near the (WWTP).

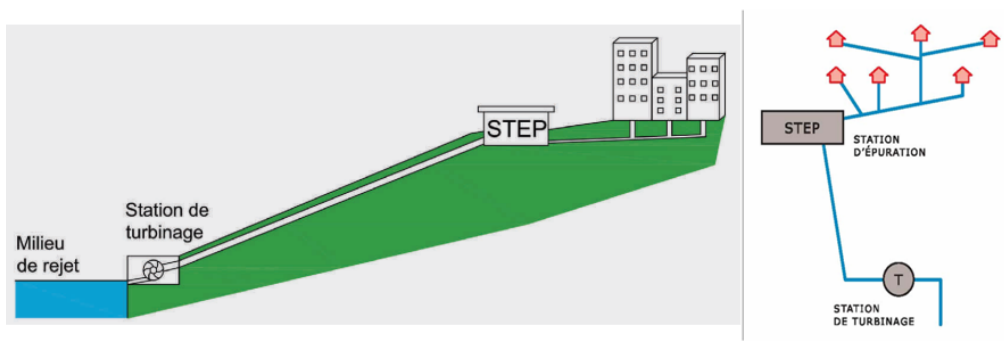


Figure 2.2: Turbination after treatment (MHylab, 2008)

⇝ Compared to conventional hydroelectric installations, turbines on waste water has certain peculiarities:

- Water quality: the presence of coarse matter in raw water untreated, which may clog the pipe and turbine, makes it mandatory the presence of a screen/screen and a basin upstream of the pipe forced. In addition, the high concentration suspended solids can damage the turbine, and cause therefore more frequent maintenance and replacement of the turbine. This problem does not arise a priori for turbination of treated water, including quality is similar to river water.

- Network loading: the waste water networks being free surface, a new penstock will have to be built to transport the water between the water intake and the turbine.

2.3 Methodology

The study focused on the energy potential around the Wastewater treatment plan, i.e. turbines before treatment and turbines after treatment. The available energy potential has been defined according to equation (2.1), where E_{prod} (kWh/y) denotes the electricity produced per year, ρ (kg/m^3) the density of the waste water, H_{nett} (m) the fall clear, $V_{waste\,water}$ (m^3/y) the volume of wastewater treated annually and η the overall yield of the installation.(Bousquet et al., 2015).

$$E_{prod} = \eta\rho g\, H_{nett}\, V_{waste\,water} \tag{2.1}$$

2.4 Profitability of facilities

Once the potential sites have been identified, the profitability of each site has been assessed. For this, a tool was created to calculate the optimal sizing to maximize the profitability. The following optimization variables were used in the calculation:(Bousquet et al., 2015)
The installation design flow, selected at from the classified flow curves;
- The speed of the water in the pipe (between 1 and 6 m/s), which influences the diameter of the pipe and the pressure drops;
- Possible technologies for the site: 4 types of turbine were considered (Pelton turbine, Kaplan turbine, reverse pump and hydraulic screw), corresponding to technologies usable in mini-hydraulics (Chapallaz & Eichenberger, 1992) , and allowing cover all power ranges.

All the sizing possibilities of each site potential were calculated based on these three variables. Then, for each sizing, the investment total necessary for the development of the installation was assessed according to the various components of the installation. The consideration of the different costs is presented in table (2.1).

Profitability was then determined using the present value net (PVN) after many years (chosen amortization period of the project). Annual revenue from the potential facility, present in the calculation of the (PVN), were calculated with cost-based compensation, the calculation of which is defined in the Ordinance on energy (Hottelier & FOËX, 2016), and which depends on the equivalent power, of the fall, and the

Table 2.1: Distribution of costs between turbines after treatment with Wastewater treatment plan and turbination before treatment at Wastewater treatment plan (Bousquet et al., 2015)

Element	After treatment	Before treatment	Cost based on...
Conduit	✓	✓	Diameter and length
Turbo generator	✓	✓	Power installed
Pretreatment tank	×	✓	Power installed
Connection	✓	×	Fixed price
Access road	✓	×	Fixed price
Local	✓	×	Fixed price

share of the cost related to water management in the total cost of the project.

For this study, the optimization of the sizing is based on the cost price, that is to say that the optimal sizing chosen is that which allows to obtain the cost price minimum. However, it is the (PVN) calculation that helps determine if a site is profitable.

2.5 Existing case

2.5.1 Wastewater treatment plan of AÏRE, GENEVA

characteristics :

Gross drop	$7(m)$
Nominal flow	3200 (l/s)
Power	200 (kW)
Production	260 (MWh/y)
Turbine type	Kaplan turbine

The installation of the WWTP of Air in Geneva is an example of water turbination after treatment. It corresponds to a typical case of a low drop installation and significant flow in an agglomeration.

2.5.2 Wastewater treatment plan of PROFAY, BAGNES

characteristics :

Gross drop	449 (m)
Nominal flow	100 (l/s)
Power	350 (kW)
Production	851 (MWh/y)
Turbine type	Pelton

The installation of the WWTP of Profay is the only example of turbination on the front waters treatment in Switzerland. A part of the waters of the urban area of verbier is pretreated and then turbinated 450 meters lower down at the Profay sewage treatment plant.

2.6 Sites selection

Whether for surface water or network water, the following classification is adopted for the selection of sites (MHylab, 2008) :

Interesting site at low or medium term A site is considered "interesting in the short or medium term" if the on-site investigations have made it possible to define an a priori interesting potential from a technical and economic point of view. In other words, a site can be qualified as interesting if it does not present major difficulties of realization, that it is from a technical or environmental point of view and that the foreseeable production allows a priori sufficient investment for allow its realization. These sites can be implemented in the short or medium term.

Site interesting in the long term A site is considered as such if: the investigations on site did not make it possible to determine a clear trend, the site was not visited, but could be interesting. a strong environmental constraint may apply they can be achieved in the medium-long term.

Uninteresting, unsuccessful site A site is considered as such if the potential which is not yet exploited today presents too many technical or environmental difficulties or even if it does not seem a priori possible to make it profitable.

Site or project not retained within the framework of this mandate because it does not represent a potential that is still exploitable

These are the sites:

- ▷ Intended for a merger project.
- ▷ Currently in service for which we have not identified any potential for improvement.

It may be noted that a site in service may have an additional potential that is not yet exploited, which may be either interesting in the short, medium or long term, or not.

2.7 Conclusion

High energy prices are forcing operators of sewage systems and wastewater treatment plants to make intensive use of the existing potentials for increasing their own energy production. So many measures have already been implemented, and as a result, hydroelectric energy is being increasingly investigated to make the most of the massive energy stored in wastewater.

Currently, there is satisfactory progress in this field. At the world level, there are many electrical plants that use wastewater to produce electrical energy considered sufficient to feed water purification plants with part of their electricity needs.

CHAPTER 3

CASE STUDY: BISKRA CITY

3.1 Introduction

BECAUSE of the huge amount of energy needed for wastewater collection and treatment more and more effort is being expended to recover energy in the urban water cycle. Often renewable energy facilities are constructed in order to reduce the overall demand of energy supply taken from the power grid. Small hydropower solutions in combined sewer systems may be part of this strategy. This paper gives an overview of the approaches attempted, suitable techniques, and restrictions and boundary conditions which have to be considered for an operation of small hydropower concepts in urban drainage.

3.2 Used methods

- ⊛ Topographic analysis of the city of Biskra.
- ⊛ Calculation of the available volumes of waste water discharged.
- ⊛ Determination of energy potential.
- ⊛ Numerical optimization of the small hydropower plan.
- ⊛ wastewater quality.
- ⊛ Search for waste water resistant materials.

3.3 Interesting potential in water treatment

We just talked about the opportunity to exploit the hydraulic potential of the wastewater network , by using a system of hydraulic energy recovery.

This study clearly shows the interconnection between the production field of energy and effluent treatment industrial or urban.

This energy is characterized by:

- Clean and safe energy.
- Easy to use.
- Unlimited hydroelectric power.
- Reduced use of traditional energy resources harmful to the environment.

3.4 Energy Autonomy of the station

To increase its energy autonomy of the station, the energy consumption of machines and lighting systems. a turbine that recovers the energy produced by the fall of purified and also installed water. if its environmental balance is favourable, its economic interest is less because of the cost of its maintenance.

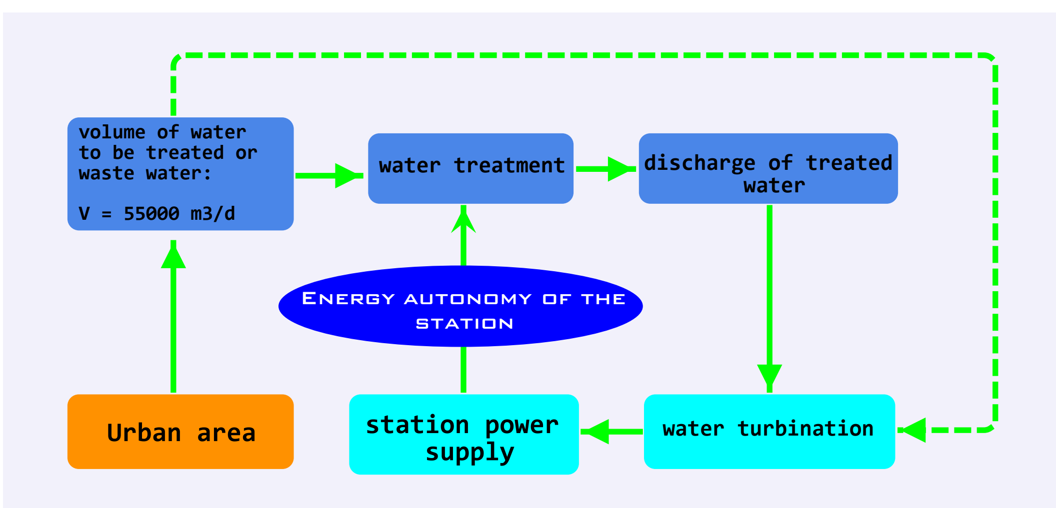


Figure 3.1: Energy autonomy of the wastewater treatment plant in the city of Biskra

3.5 The Area under Analysis

3.5.1 Topography of the site

The topography of Biskra like any desertic area suggests a potential, if not large, energy potential Unused sewage water. In our work presented in this thesis, we will study the case of Medina Biskra, where to look for High and low points of the sewage system.

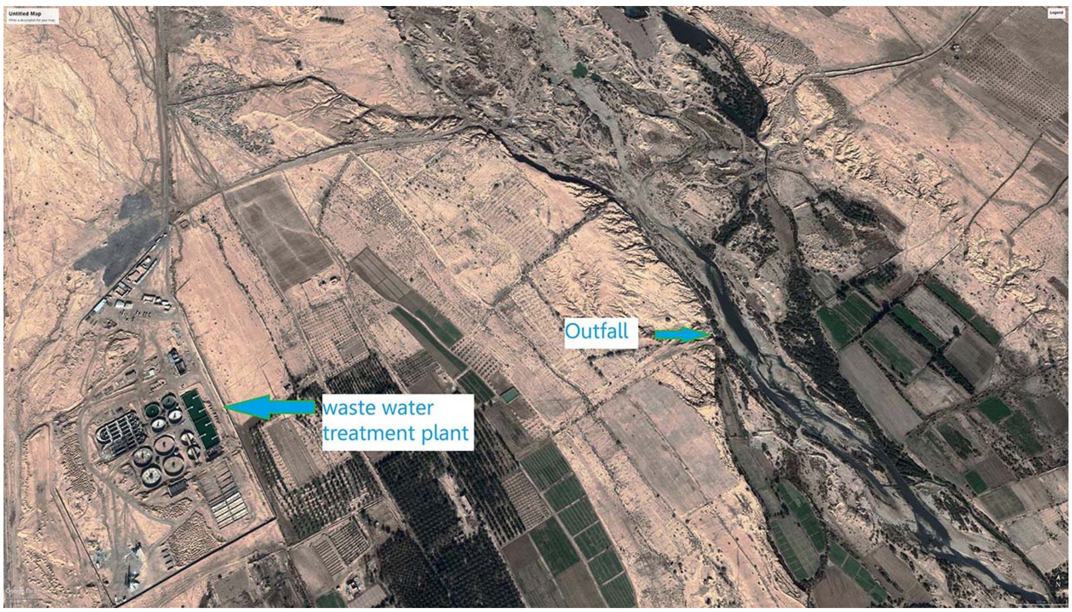


Figure 3.2: An aerial view of the wastewater outfall of the city of Biskra

3.5.2 Available data of the site

3.5.2.1 Introduction

The evaluation methodology is based on available data On the downstream site, to obtain more reliable results, accurate data and high quality data must be obtained.

3.5.2.2 Fall analysis

The analysis of the used waterfall was carried out on land by students from the University of Biskra.

- Nominal diameter of the outlet channel: $DN = 1500(mm)$

- Gross fall $H = 4(m)$
- Nominal flow rate: $Q = 0.637\ (m^3/s)$

Figure 3.3: Wastewater waterfall

Figure 3.4: Wastewater outlet via main channel

3.6 Choice of turbine type

Hydropower turbines use water pressure to rotate its blades and generate energy. Selecting the appropriate type of turbine depends primarily on available head and less so on available flow rate. The three primary types of turbines are: the Pelton turbine, for high heads; the Francis turbine, for low to medium heads; and the Kaplan turbine for a wide range of heads (see Figure 3.5 below).

The intersection between the flow rate point and the head of water gives the appropriate type of turbine. From the intersection point we conclude that the appropriate turbine is: ***Kaplan turbine***.

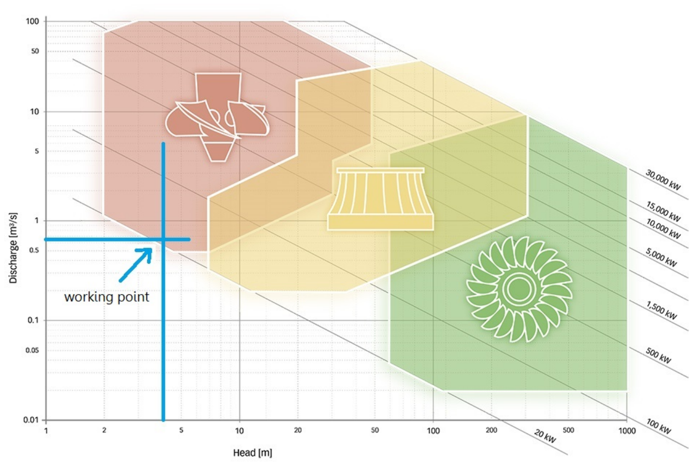


Figure 3.5: how to choose the type of turbine

3.7 installation scheme

The grid prevents large objects from passing into the collection basin and the collection basin collects the wastewater in a middle channel in order to pass it through the turbine below.

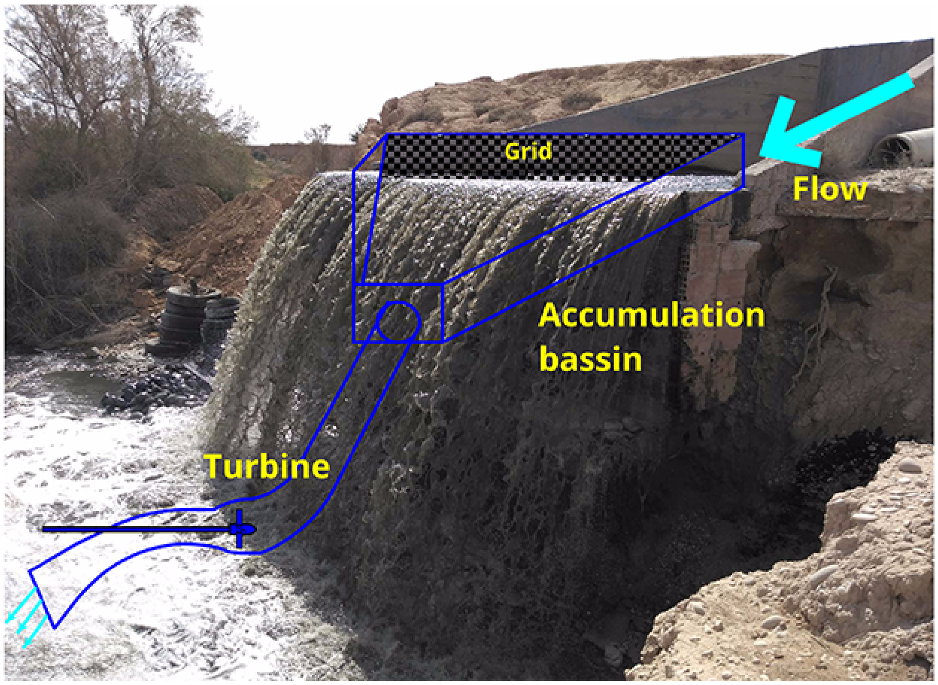


Figure 3.6: Real picture of the turbine model and its various elements

There is no specific rule for calculating the dimensions of the accumulation tank, but we are trying to find dimensions that are ideal in terms of the technical side so that there is no water leakage and from the economic side so that the costs are minimal.

Here we will choose all the wall heights are identical.

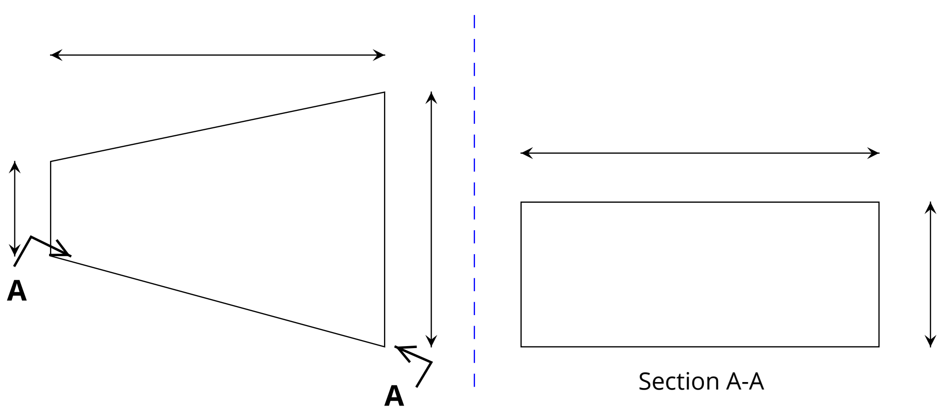


Figure 3.7: The accumulation basin

The figure (3.8) represents a diagram of all parts of the turbine and how they are sequenced.

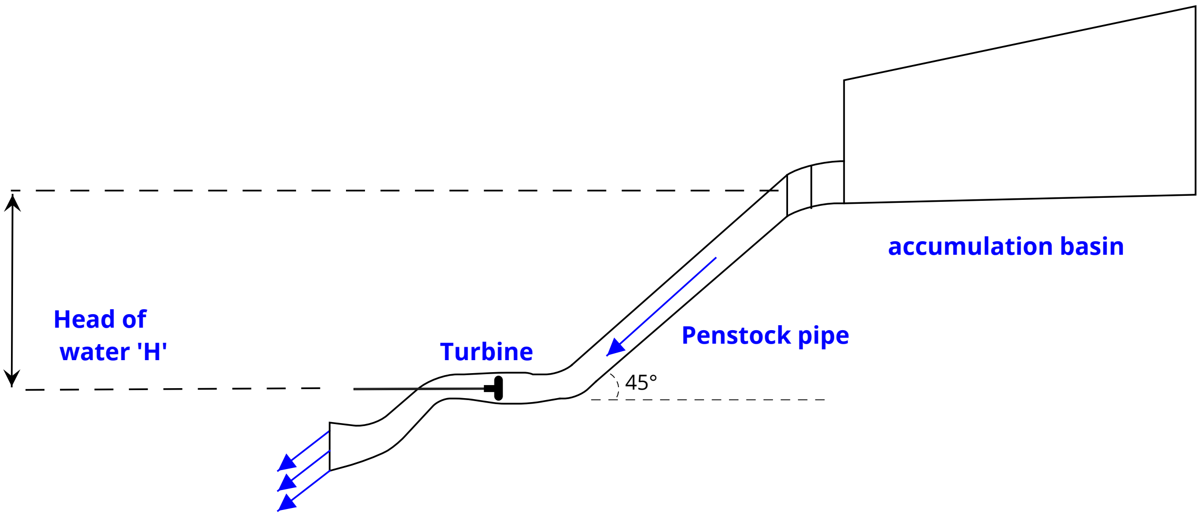


Figure 3.8: the general scheme of the turbine installation

3.8 Calculation of the Optimum diameter of Penstock based on empirical relations

Various researchers have proposed the methodology and relations for the optimum design of penstock. These relations are either empirical relations developed by analysing and correlating statistical data of existing/installed projects designed as per past practice minimizing annual penstock cost The available analytical relations loss whereas in addition to friction loss, there are other losses such as losses at specials tri/bifurcation etc.), losses at valves and inlet which are not considered while optimizing the penstock design.

Annual penstock cost comprises of investment cost on penstock material, excavation for penstock, concreting, installation, operation, maintenance. depreciation and cost of energy loss caused by head loss. The available empirical relations can be grouped in different categories based on parameters used to determine the optimum penstock diameter.(Kumar & Singhal, 2015)

3.8.1 Empirical Relations Based on Penstock Discharge (Q)

Warnick (1948) developed formula for optimum diameter of penstock pipe (D_e) for small hydro projects in terms of rated discharge (Q) (Kumar & Singhal, 2015)

$$D_e = 0.72 \times Q^{0.5} \tag{3.1}$$

In this case: D_e =$0.72 \times 0.637^{0.5} = 0.575(m)$

3.8.2 Empirical Relations Based on Penstock Discharge (Q) and Rated Head (Hr)

(USBR, Engineering Monogram No. 3, 1986) and (Fablbusch, 1987) have developed the relations for economic penstock diameter in terms of rated discharge and rated head. These relations are shown as equation(3.2) and equation(3.3)

$$D_e = 1.517 \times \frac{Q^{0.5}}{H_r^{0.25}} \tag{3.2}$$

In this case: D_e = $1.517 \times \frac{0.637^{0.5}}{4^{0.25}} = 0.856(m)$

$$D_e = 1.12 \times \frac{Q^{0.45}}{H_r^{0.12}} \tag{3.3}$$

In this case: D_e = $1.12 \times \frac{0.637^{0.45}}{4^{0.12}} = 0.774(m)$

3.8.3 The optimum results

Based on the previous results, we conclude that:

- the diameter 575 mm is too small compared to other results.
- the ideal value for the channel diameter is approximately 800 (mm).
- The diameter on the market is ND 900 millimetres, thickness 53.3 millimetres and the internal diameter 793,4 millimetres.

3.9 calculation of the available net charge

Obviously, the flow of water in the channels, whether free surfaces or inside a canal under pressure, results in a loss in the head of water, and considering that the passage through the turbine is very small, then we neglect the loss in the linear head and we calculate the loss resulting from the singularity of the turbine.

On way losses may be calculated to assume that across any component the total head loss is proportional to velocity head at exit (Ingram, 2009):

$$\Delta H = k \left(\frac{V^2}{2g} \right)_{exit} \tag{3.4}$$

With:

- ΔH : the loss of head.
- k : the coefficient of the singularity.
- V : the velocity of water.
- g : the gravitational acceleration.

3.9.1 determining the singularity points

3.9.1.1 Connection of the penstock with the accumulation basin

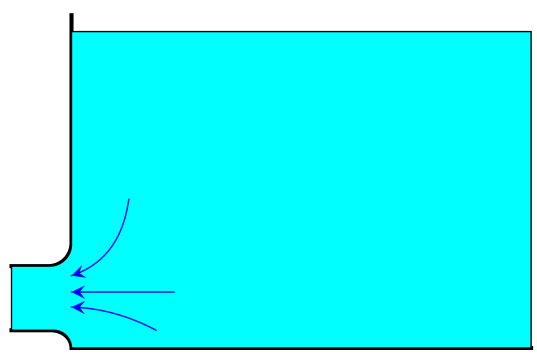


Figure 3.9: Descriptive scheme of the connection of the penstock with the accumulation basin

This singularity is without protrusion inside the tank, with rounded profile connection.

► In this case: (K=0.05). (LENCASTRE, 1996)

3.9.1.2 elbows (45 degree)

We have two turning points(elbows) in the system, one at the outlet of the tank and one at the meeting point with the turbine.

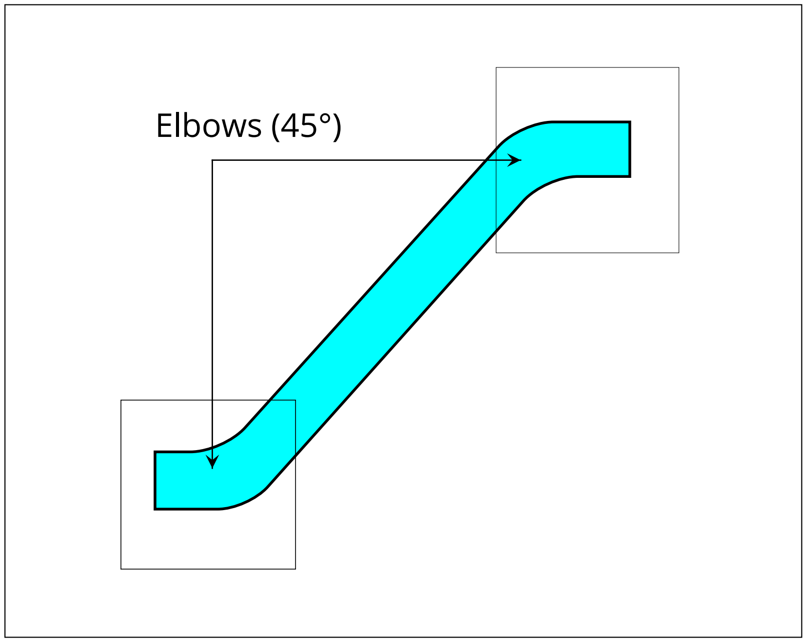


Figure 3.10: the position of the elbows in the system

In this case, parameter $K = 0.1$ (LENCASTRE, 1996).

And we have two 45° elbow and the connection of the penstock with the accumulation basin. Therefore, the equivalent coefficient k of the system is :

$$k_{eq} = 0.05 + 2 \times 0.1 = 0.25$$

3.9.2 Calculation of the head loss

We have the continuity equation of an incompressible flow and for a circular pipe

$$V = \frac{Q}{S} = \frac{4Q}{\pi D^2} \tag{3.5}$$

Therefore, the velocity of water will be:

$$V = \frac{4 \times 0.637}{\pi \times 0.7934^2} = 1.29\ (m/s)$$

By using the equation (3.4), We find that the value of the head loss is:

$$\Delta H = 0.25\left(\frac{1.29^2}{2\times 9.81}\right) = 0.021\ (w.c.m)$$

We consider that the water when it comes out of the drainage channel is carrying energy, and therefore we neglect all the losses of head because it is very small and it neutralizes the energy that the water comes out to the drainage channel.

3.9.3 Infer water head when crossing the turbine

From previous calculations, we conclude that the head of water when crossing the turbine is 4 water column meter.

3.10 Hydroelectric production

The calculation of the energy potential is based on the formula (1.2) from chapter 1, which makes it possible to calculate the available power(We consider that the yield of the turbine is in the range of 0.8).

$$P_h = \eta\rho g H Q = 0.8\times 1000\times 9.81\times 4\times 0.637 = 20783\ W \approx 21\ W$$

Hence, the electric power produced is in the range of 21 kilowatts, which is considered significant energy for operating several machines at the station.

In this case we consider the wastewater density equal to one, As the wastewater treatment plan is in progress, and when complete, the turbinig system will now be after treatment and the water quality will become natural quality.

3.11 Chemical factors affecting corrosion

Dissolved substances in water have an important effect on both corrosion and corrosion control. This section provides a brief overview to point out some of the most important factors.

3.11.1 General

Table (3.1) lists some of the chemical factors that have been shown to have an important effect on corrosion or corrosion control. Several of these factors are closely related, and a change in one changes another. The most important example of this is the relationship among pH, carbon dioxide (CO2), DIC concentration, and alkalinity. Although CO2 is frequently considered to be a factor in corrosion, there is no clear evidence that direct corrosion reactions include CO2 as a reactant (Letterman, 1999)

Table 3.1: Some chemical Factors Influencing Corrosion and Corrosion Control(Letterman, 1999)
.

Factor	Effect
pH	Low pH may increase corrosion rate and the strength of oxidizing agents; high pH may protect pipes by favoring effective passivation films and decrease corrosion rates; possibly causes or enhances dezincification of brasses.
Alkalinity/DIC	May help form protective carbonate or hydroxycarbonate films; helps control pH changes by adding buffering. Low to moderate alkalinity reduces corrosion of most materials. High alkalinities increase corrosion of copper at all pHs, and lead at high pH.
Hardness (Ca and Mg)	Ca may precipitate as $CaCO_3$ and thus provide protection and reduce corrosion rates. May enhance buffering effect in conjunction with alkalinity and pH.
Chloride, sulfate	High levels increase corrosion of iron, copper, galvanized steel, possibly lead.
Natural colour, organic matter	May decrease corrosion by coating pipe surfaces over long term. Some organics can complex metals and accelerate corrosion or metal uptake, especially when surfaces are new.

3.11.2 Corrosion control alternatives

The complete elimination of corrosion is difficult if not impossible. Technologies generally exist to reduce or inhibit corrosion, though the determination of feasibility may depend mostly on economics or risk/aesthetic trade-off. Corrosion depends on both the specific water quality and materials of the pipe and the turbine in a system.

There are several approaches to control corrosion such as: Properly select system materials and adequate system design and Modify water quality.

3.12 Conclusion

The energy use of wastewater in the city of Biskra requires improvements complex and varied, time at the level of civil works as hydraulic equipment.

The project envisaged here would produce more than 21 KW of electricity, with the advantage of serving this energy during hours of high consumption.

CHAPTER 4

DESIGN AND SIMULATION OF THE TURBINE

4.1 Introduction:

THE chapter presents the analysis of the semi-Kaplan turbine (SKT) from the sewage network of the city of Biskra. The (SKT) that consists of the guide vanes and propeller turbine integrated with a synchronous generator is designed with TURBNPRO version 3.0, CFturbo version 10.4.7.30 and simulated by using Computational Fluid Dynamics (CFD) in Ansys CFX 2020 R2 Academic version .

4.2 Material and global characteristics calculations

4.2.1 Material

Most of the parts involved in the Kaplan Turbine are generally high alloy steel (Stainless Steel) because most of the parts will be in continuous contact with water and thus they have to be corrosion resistant. Moreover, stainless steel (high Cr and Ni) possesses good weldability, high strength against bending and highly machinable.

4.2.2 Global turbine parameters

Runner blade is one of the most important components in the Kaplan turbine. And to begin with the designing part of the same, parameters like power, flow rate, and runner diameter first have to be determined. Depending upon the site selected, the calculations of these parameters are done in this section. The data on which the design of the runner is based is known as main characteristics. So for the calculation of forces on the blade, the main characteristics are to be obtained.

4.2.2.1 Power

Multiplication of head of water and discharge through the turbine gives available Power.
$P_h = 21\ KW$. (From the tenth part of the third chapter)

4.2.2.2 Specific Speed

Usually, based on this parameter, hydraulic turbines are categorized. Specific speed is the speed of turbine which is identical in shape and other geometries and which works under the unit head and produces unit power. It is a dimensionless parameter.
It is given by the following equation:

$$N_s = \frac{885.5}{H_n^{1/4}} \tag{4.1}$$

Where,

- N_s Specific speed [-]
- H_n Net head [m]

In our case, we have that: $H_n = 4\ m$, therefore:

$$N_s = \frac{885.5}{4^{0.25}} = 626$$

4.2.2.3 Speed of the Runner

The Speed of the Runner is calculated by using the following formula:

$$N = \frac{N_s * H_n^{1.25}}{\sqrt{P}} \tag{4.2}$$

Based on the previous results,and by compensation we find:

$$N = \frac{626 * 4^{1.25}}{\sqrt{21}} = 772 \ \ rpm$$

From this we conclude that the turbine rotates at a speed of 772 round per minute.

4.3 Determination of turbine components dimensions

TURBNPRO is one of the best software of its kind created to develop information on hydraulic turbines, their selection and application under specific site conditions.

Procedures followed in the design process are discussed in the followings:

1. Open the software.
2. Selection Axial/Propeller option
3. Enter the data in the table (4.1)
4. Run the simulation and showing the results.

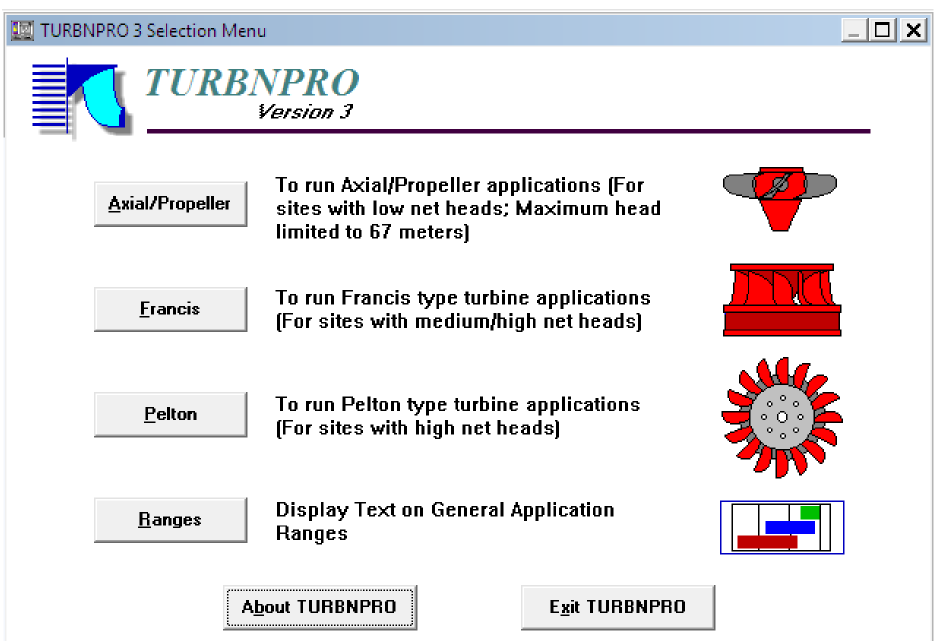


Figure 4.1: TURBNPRO 3 interface

Table 4.1: SET-UP PARAMETERS OF THE DESIGN SOFTWARE

Parameter	value
Rated discharge	0.637 m3/s
Gross Head	4.2 m
Net Head	4 m
Minimum Head	3.8 m
Water temperature	20 °C
Site elevation	69 m
Setting to Tailwater	1 m
System frequency	50 Hz

4.3.1 results of the simulation:

The first simulation results are clear in the following two figures.

```
                              TURBINE SIZING CRITERIA
                              _______________________

Rated Discharge:                  22.5  cfs       /           0.6  m3/s
Net Head at Rated Discharge:      13.1  feet      /           4.0  meters
Gross Head:                       13.8  feet      /           4.2  meters
Site Elevation:                  226    feet      /          69    meters
Water Temperature:                68  Degrees F   /          20  Degrees C
Setting to Tailwater:              3.3  feet      /           1.0  meters
Efficiency Priority:                              8
Rated Head/Best Eff Head:                         0.850
System Frequency:                               50  Hz
Minimum Net Head:                 12.5  feet      /           3.8  meters
```

Figure 4.2: Turbine sizing criteria

```
                      AXIAL/PROPELLER TURBINE SOLUTION DATA
                      _____________________________________

Arrangement:                   HORIZONTAL TUBULAR
Unit Regulation Capability:    KAPLAN
Intake Type:                   HORIZONTAL AXIAL
Draft Tube Type:               S-TYPE
Runner Diameter:                   16.7  inches    /          425     mm
Unit Speed:                       750.0  rpm
Multiplier Efficiency Modifier:     1.000
Flow Squared Efficiency Modifier:   0.0000
Specific Speed at Rated Net Head -        (US Cust.)          (SI Units)
             At 100% Turbine Output:        166.8               635.9
             At Best Efficiency Condition:  157.7               601.2
Best Efficiency Net Head:          15.4  feet      /            4.7  meters
```

Figure 4.3: Turbine solution data

Through the simulation results showing in Fig. (4.2) and Fig. (4.3) ,we conclude that the diameter of runner is (425 mm). The dimensions of the turbine are showing in Fig. (4.4). The number of blades is chosen as *four* and the shape of blade is aerodynamic in nature. The diameter of hub is (172.2 mm).

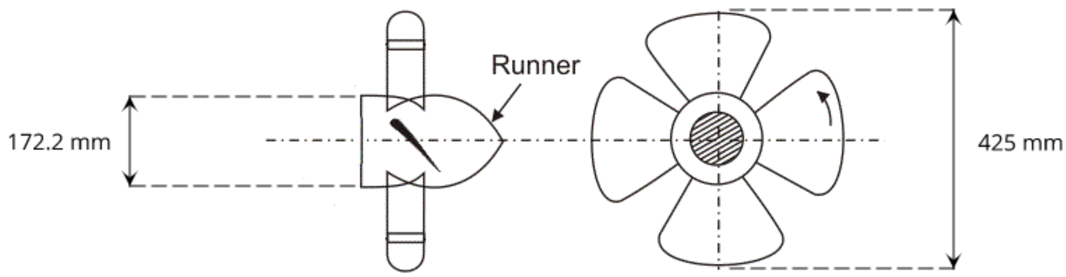


Figure 4.4: Dimensions of Kaplan turbine

The Fig. (4.5) shows the other part of the optimization process of the turbine and it's: the intake of the turbine (**HORIZONTAL AXIAL)**, Turbine dimensions, Draft tube type **(S-TYPE)** and its dimensions and other miscellaneous dimensions.

```
                          DIMENSIONAL DATA
                          ________________
.................................................................................
    Intake Type:     HORIZONTAL AXIAL
                                  inches      /         mm
      Inlet Diameter:              30.0                 762
      Runner Centerline to Inlet
         Ranges From:              21.8                 553
         To:                       26.8                 680


.................................................................................
    Draft Tube Type:     S-TYPE
                                  inches      /         mm
      Centerline to Invert:        41.8                1063
      Overall Length:              83.7                2125
      Exit Width:                  35.1                 893
      Exit Height:                 23.4                 595
.................................................................................
    Miscellaneous:
                                  inches      /         mm
      Wicket Gate Height:           5.8                 147
      Wicket Gate Circle Diameter: 21.1                 537
      Runner Centerline to
         Shaft Coupling:           40.2                1020
.................................................................................

 **** All information listed above is typical only.  Detailed characteristics
      will vary based on turbine manufacturer's actual designs.
```

Figure 4.5: Dimensional data

SOLUTION PERFORMANCE DATA

At Rated Net Head of: 13.1 feet / 4.0 meters

% of Rated Discharge	Output (KW)	Efficiency (%)	cfs	m3/s
** 143.3	33	91.8	32.2	0.9
100	23	92.0	22.5	0.6
* 89.3	21	92.1	20.1	0.6
75	17	91.6	16.9	0.5
50	11	89.2	11.2	0.3
25	5	82.9	5.6	0.2

** - Overcapacity
* - Best Efficiency Condition at Rated Net Head

At Maximum Net Head of: 13.8 feet / 4.2 meters

Sigma Allowable	Max. Output (KW)	Efficiency (%)	cfs	m3/s
1.607	35	91.8	32.5	0.9

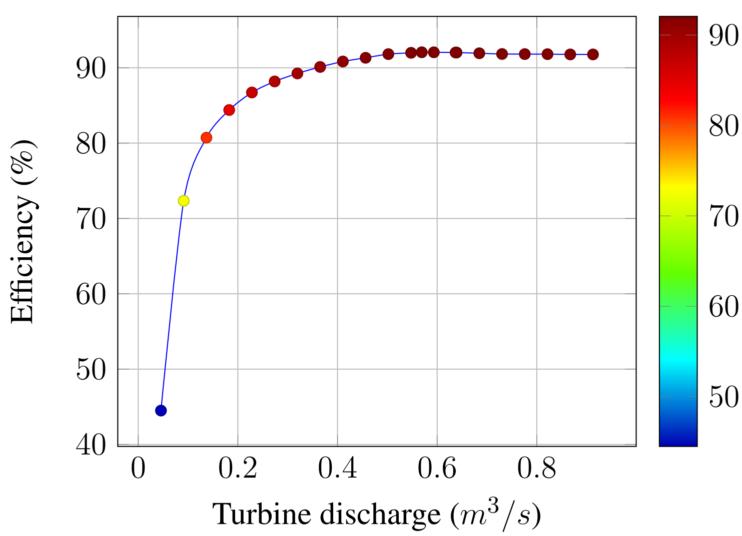
At Minimum Net Head of: 12.5 feet / 3.8 meters

Sigma Allowable	Max. Output (KW)	Efficiency (%)	cfs	m3/s
1.779	31	91.5	31.7	0.9

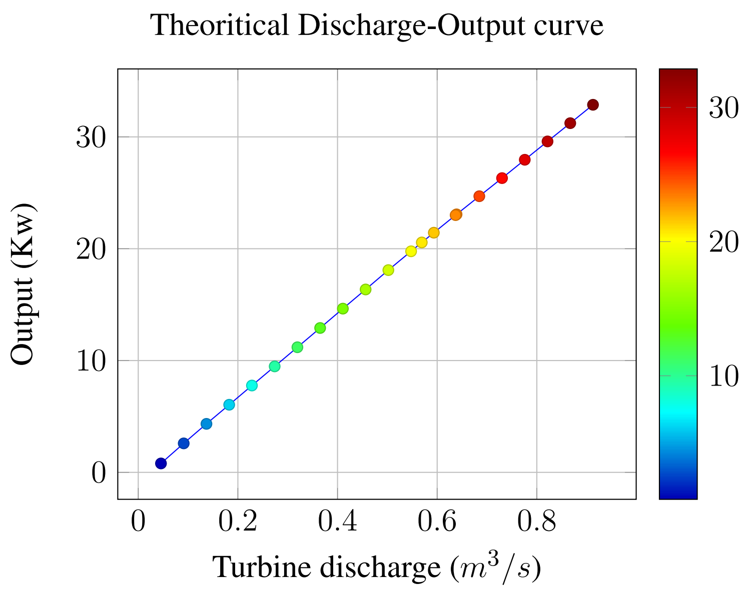
Figure 4.6: Solution performance data

The calculation results of TURBNPRO software for the Kaplan turbine are presented in Fig (4.6) in the form of script and to simplify observing the results, we convert them into graphs as follows:

Theoritical Discharge-Efficiency curve



As the flow-efficiency curve shows an increase in the turbine efficiency with an increase in the flow of wastewater where we notice that the the efficiency is small except in cases where the flow is very small and this is a precursor to occurrence.



the flow-output curve shows an increase in the turbine output with an increase in the flow of wastewater and this normal where electrical power is in terms of waste water flow in this case.

4.3.2 General results about Tabular turbine S

This type of turbine has a horizontal axis and axial inflow of water onto the runner. It is equipped with an S-shaped draft tube with one or two bends. The shaft runs through the bend of the draft tube out of flow tract. The generator is located outside of the flow tract. where Figures (Fig. (4.7), Fig. (4.8) and Fig. (4.9)) indicates the dimensions of the turbine external components calculated by **TURBNPRO**.

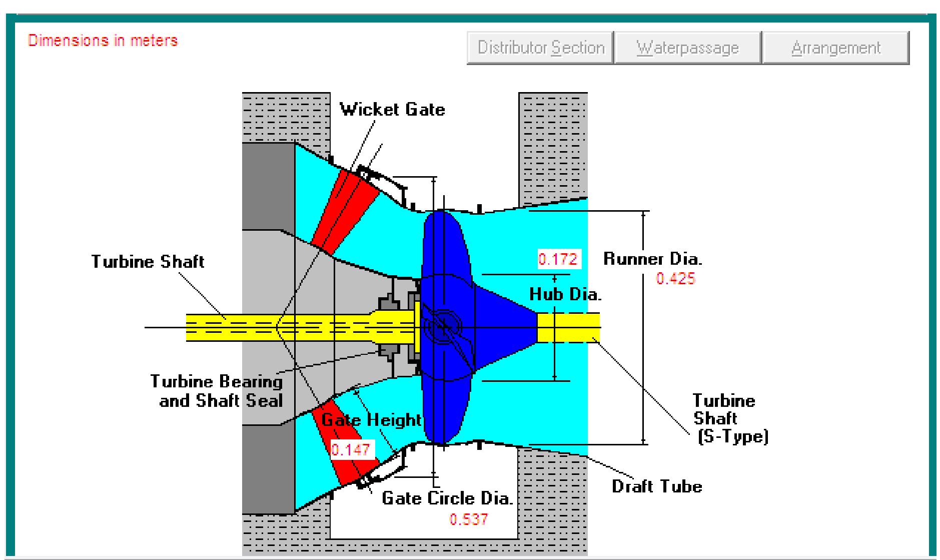


Figure 4.7: Distribution section

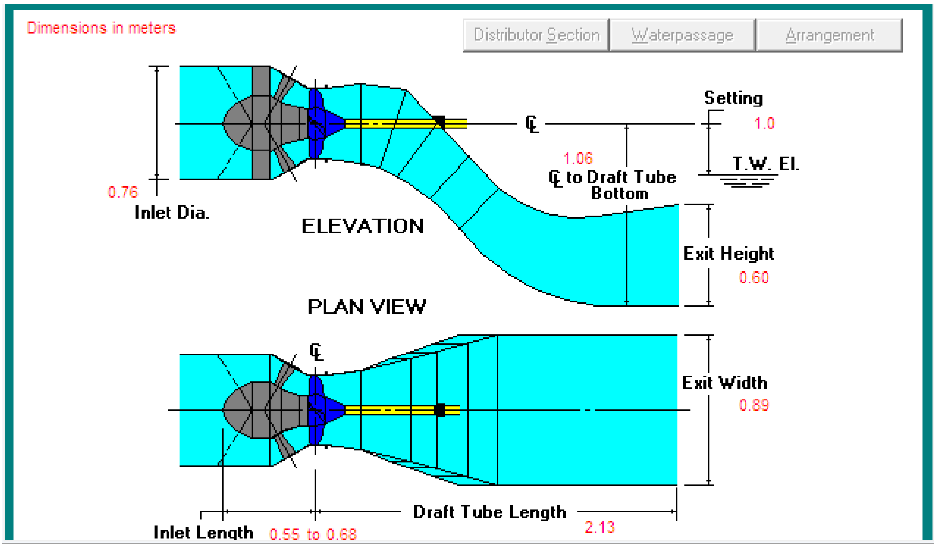


Figure 4.8: Water passage

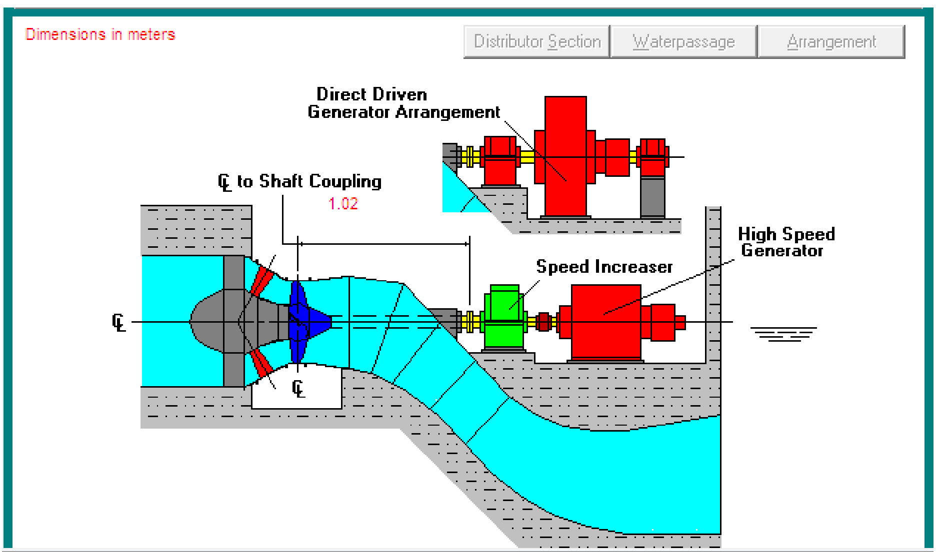


Figure 4.9: Arrangement

4.4 Turbine design and model geometry

4.4.1 Introduction to CFturbo

CFturbo is made to interactively design radial, mixed-flow and axial turbo machinery: pumps, ventilators, compressors, turbines. The software is easy to use and does enable quick generation and variation of impeller, stator and volute geometries. Several models can be displayed, compared and modified simultaneously.

It contains numerous approximation functions that may be customized by the user in order to implement user specific knowledge into the CFturbo-based design process. In spite of the creation of semi-automatic proposals, fundamental experiences in turbo-machinery design are helpful but not necessary.

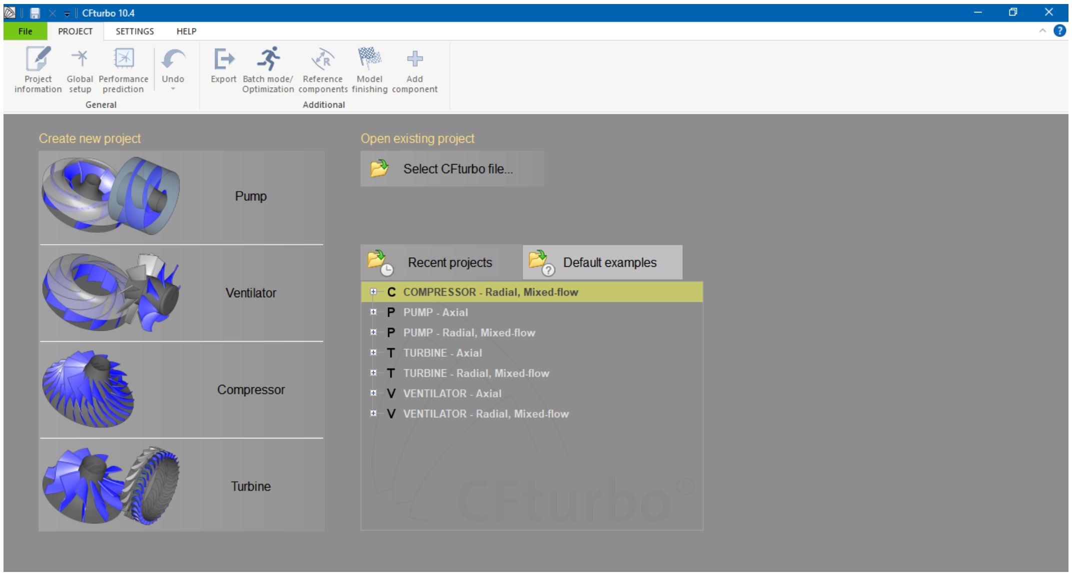


Figure 4.10: CFturbo interface

4.4.2 Set-up turbine parameters

Consider a turbine consisting of a stator and a rotor, the cascade and meridional views are shown in figure (4.11) along with the coordinate system. There are three points that are of interest to us entry to the stator, the gap between the stator and the rotor and exit from the rotor, these are labelled 1,2 and 3 respectively also in Figure (4.11) . The combination of rotor and stator is called a "stage".

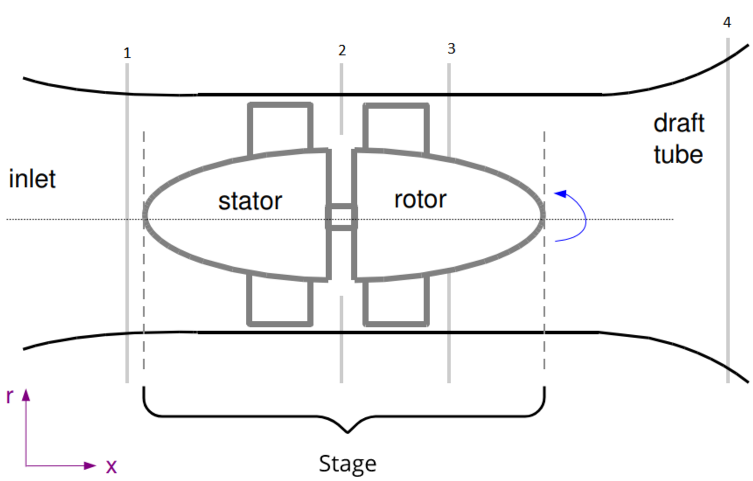


Figure 4.11: General arrangement of Kaplan turbine

At point 1 we have an incoming velocity but as the stator is not moving there is no relative motion between the incoming flow and the stator so there is no velocity triangle to draw at this point.
At point 2 the flow leaves the stator and enters the rotor. Here there are two frames of reference, the flow viewed from the point of view of the stator and the point of view from the moving rotor.
At point 3 the flow leaves the rotor and exits the stage. Again there are two frames of reference, or points of view for the flow. That found by viewing from the moving 1ofor and that found by viewing from outside the rotor where there is no motion.
In order to carry out a preliminary blade analysis consider a mean radius through the machine. In order to draw or manufacture the blades you will need to know the inlet and exit angles of the stator (α_1 and α_2) and the rotor (β_2 and β_3). This is shown in Figure (4.12).
We can now draw the velocity triangles for point 2 and point 3 in the stage, this is shown in Figure (4.13).

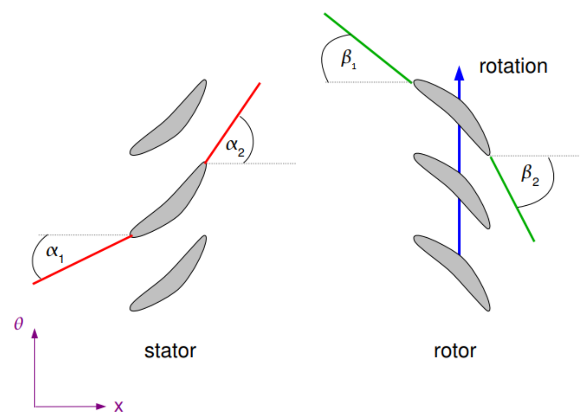


Figure 4.12: Angles that need to determined for design

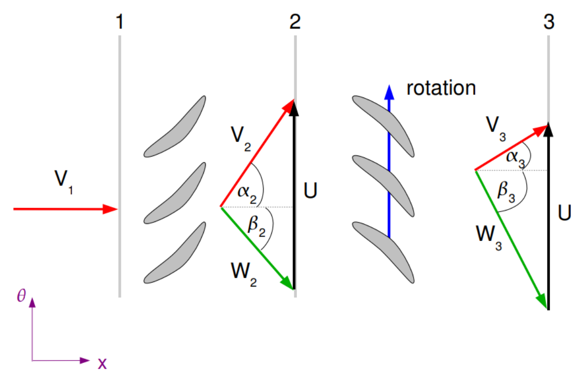


Figure 4.13: Velocity Triangles for the Axial Flow Kaplan

4.4.2.1 Parametrized geometry

The geometric model is now a fully parametrized one because the crucial parameters are now fixed. Those parameters are given in Table (4.2).

Table 4.2: Global setup

Name	Description	value
Q	Flow rate	0.637 m3/s
H	Head	4 m
n	Revolutions	772 rpm
pt	Total pressure	0.4 bar
T	water temperature	20 °C

Table 4.3: Impeller setup

Name	Description	value
d_2	Impeller diameter	425 mm
d_n	Hub diameter	172.2 mm
n_{bl}	Number of blades	4
β_1, β_2	Blade angles	Automatic calculation
$-$	other parameters	Automatic calculation

4.4.2.2 Results of CFturbo optimization of the runner blades

velocity triangle at the tip (shroud) and at the hub are shown in Figure (4.16) and it was calculated based on the results on the table from the figure (4.15) .

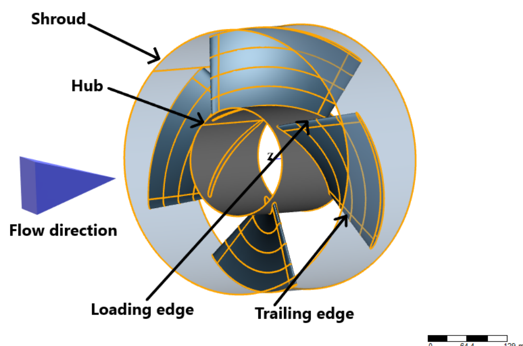


Figure 4.14: Schematic representation of the Kaplan turbine blades and edges

Span		ßB1 [°]	ßB2 [°]
Hub	1	42.1	52.4
	2	36.5	46.1
Middle	3	31.0	39.8
	4	25.4	33.5
Shroud	5	19.9	27.2

Figure 4.15: Blade angles of Kaplan runner

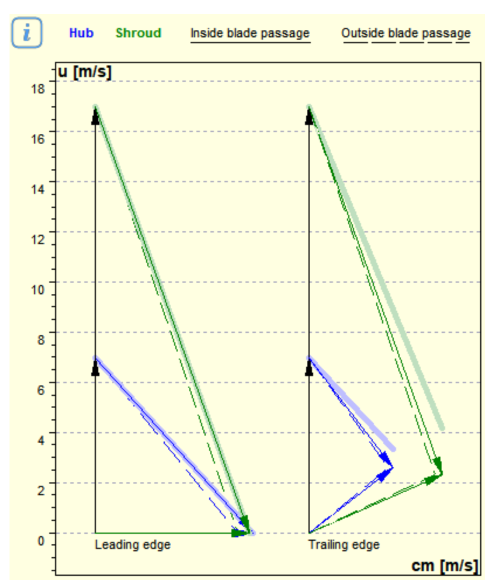


Figure 4.16: Velocity triangle of Kaplan runner

Using the algorithms of the CFturbo program, we consider that one blade is distorted into five sections, The angle "β" and the radius "r" of each section gives conclusions on the distortion of the blade.

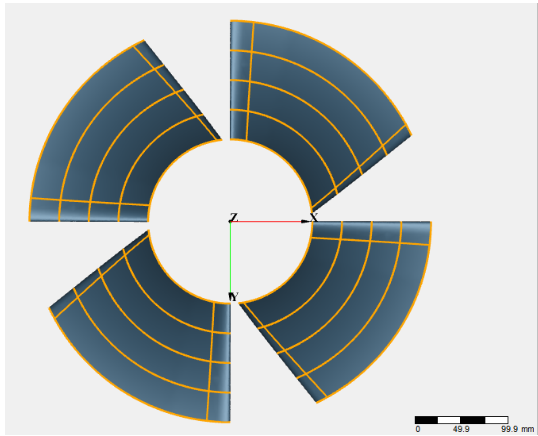


Figure 4.17: Vertical view of the five blades sections

Using all available data, a 3D CAD model based on the available data from the analysis was accomplish using Ansys Space-claim software..

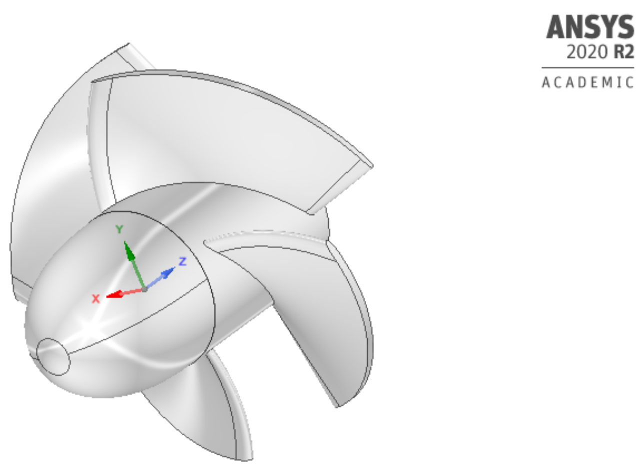


Figure 4.18: 3D CAD model of Kaplan turbine runner

4.4.2.3 Guide vane optimization

User the user guide for the CFturbo program, Which is based on real data and empirical formula, we find that the number of guide vane is ten. Other dimensions and angles put directly into the final design.

4.5 Numerical modelling

4.5.1 Mesh grid generation

The computational mesh was prepared in ANSYS Meshing application 2020 R2 based on the CAD model (Fig. 4.19).

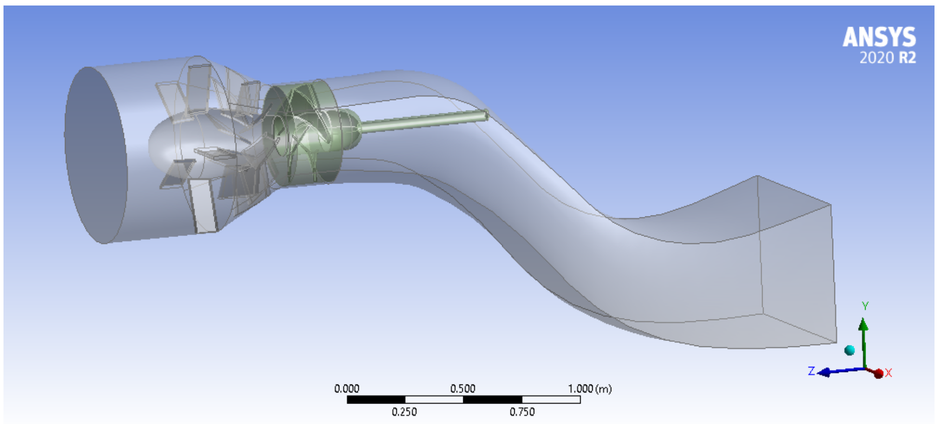


Figure 4.19: CAD model of the whole turbine system

for non-conformal components: the inlet pipe, hydroset tube that includes the guide vanes and the draft tube. The components were selected considering it as one structure in order to optimize the mesh. Additionally, to eliminate the computational complexity of the remeshing function the turbine rotor (rotational domain) was prepared as a separate component. The curvature size function with a curvature normal angle equals 30° and minimal mesh element of 20 mm was applied.

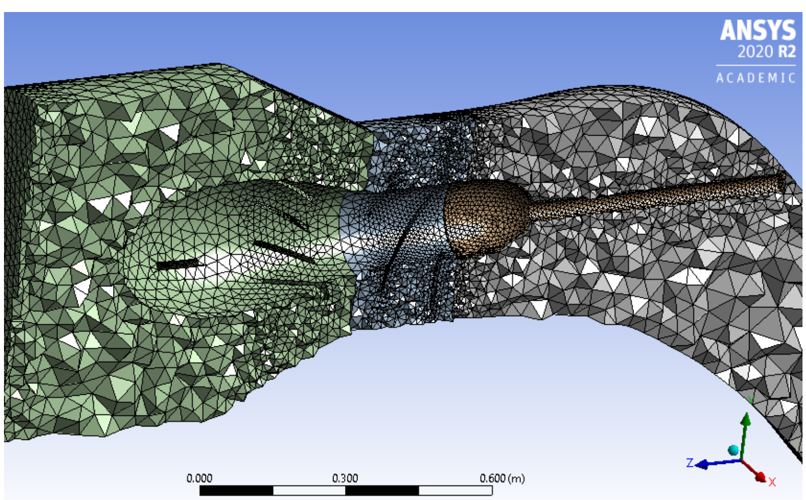


Figure 4.20: cross-section of the system mesh

The generated mesh consists of about 512K elements and 350K nodes. The mesh quality was assessed using CFX preference solver , quadratic element order and medium smoothing.

4.5.2 Boundary conditions and solver settings

At the location of the inlet boundary condition the total absolute pressure (1 atm + 0.4 bar) is given, which is the atmospheric pressure and the hydrostatic head of water while the mass flow rate is 637 Kg/s . At the outlet boundary the pressure (1 atm) because its an outlet flow. , is specified (Fig. 4.21).

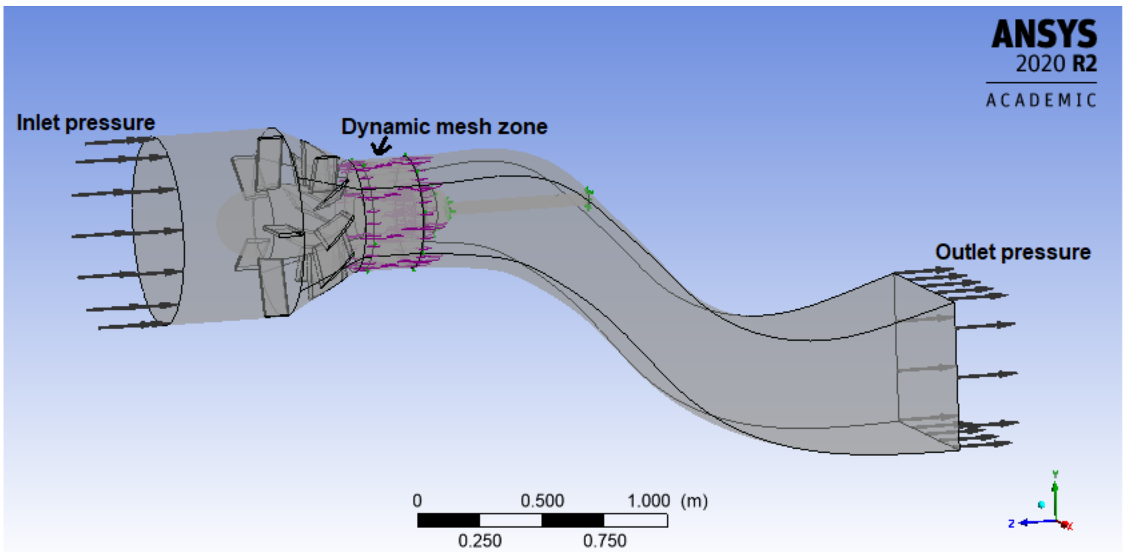


Figure 4.21: Boundary conditions scheme

The pressure based solver allows to perform calculations of the fluid flow problems using separate or split equations. In case of the transient fluid flow, complex mesh grid or large time steps, the more accurate results are obtained by using the coupled algorithm. The most important solver parameters are listed in Table (4.4).

Table 4.4: Details of solver control in flow simulation

Description	value
Equations class settings	Continuity
Turbulence model	$k - \varepsilon$
Wall function	scalable
Advection scheme	Hight resolution
Turbulence scheme	Hight resolution
Convergence conditions	Default conditions

4.6 Solution method

In order to determine the efficiency and power curves and in order to analyse the losses in a draft tube, the steady state simulation is believed to provide acceptable results. Accuracy of the prediction is sensitive to the advection scheme. Upwind, high resolution and some blend factors to blend between the first and second order advection schemes are specified to calculate the advection terms in the discrete finite volume equations.

4.7 Results and discussion

4.7.1 Streamlines and velocity vectors field

Path line (streamline) plots: Path lines are parallel to the mean velocity vector, where they trace the flow pattern using massless particles.

Figure (4.22) shows streamlines in an absolute frame of reference (YZ plane). Streamlines are traced for the stator proper (w/o pre-stator) and the rotor. It may be observed that rotor blades extract most of the angular momentum generated by the stator.

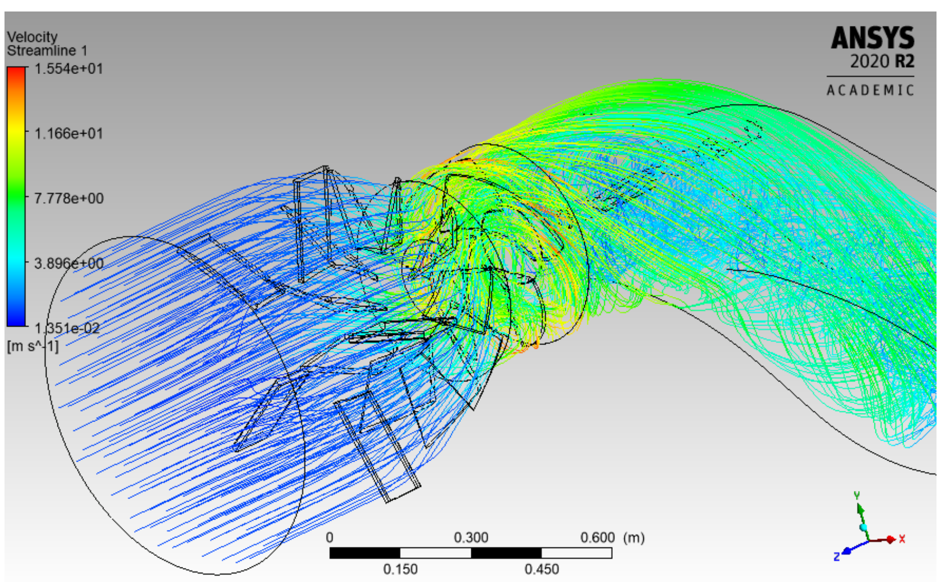


Figure 4.22: Distribution of the stream lines of the turbine

As the figure (4.23) indicates the velocity vectors field around the pre stator, the stator and the turbine. However, the flow instability occurred near the tip of the runner, velocity is increased at the centre of the runner suction side, and the flow is highly unsteady.

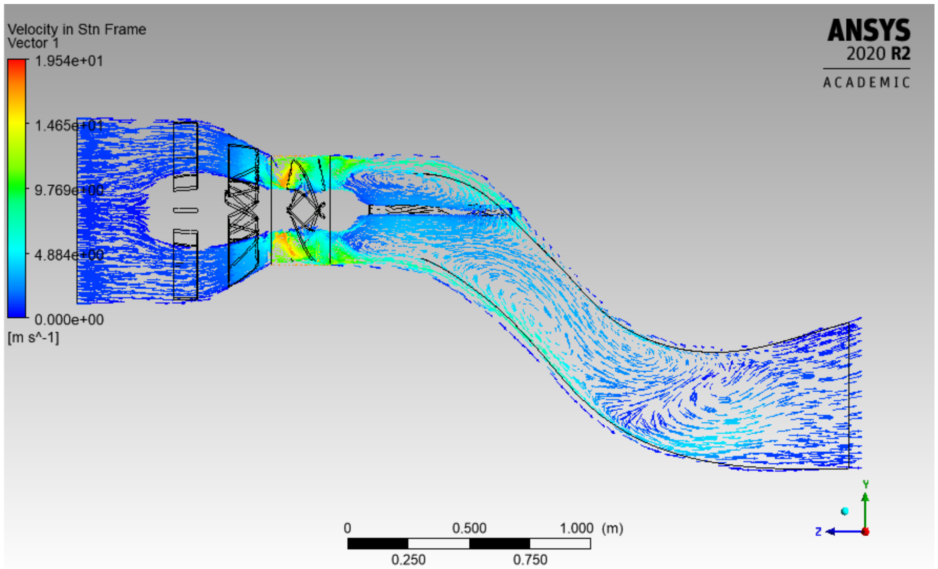


Figure 4.23: Distribution of the velocity vectors field

4.7.2 Pressure distribution

Figure (4.24) shows the total pressure contour on the pre-stator, the stator, the rotor and the draft tube .

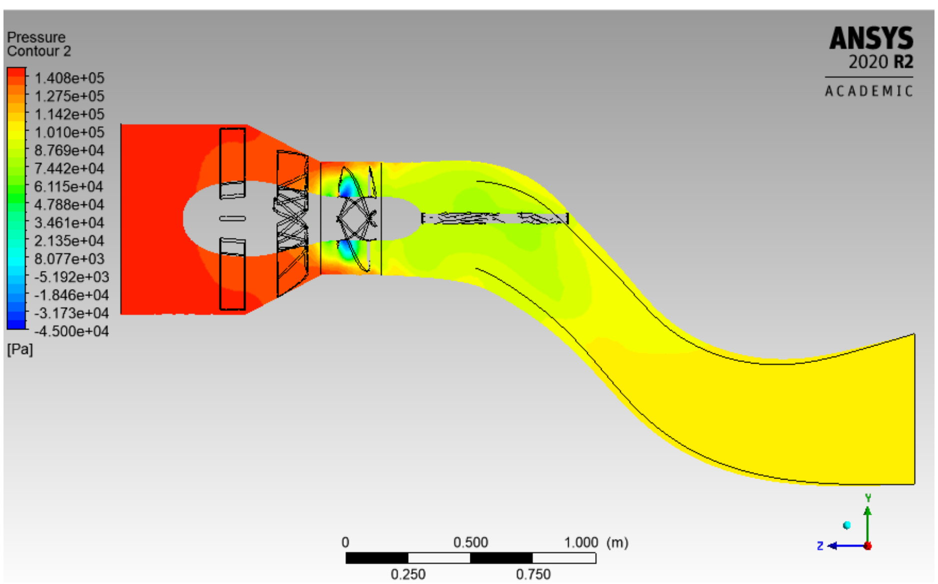


Figure 4.24: The total pressure distribution of the S Kaplan turbine system

Pressure inside turbine decreases from Leading Edge (LE) to Trailing Edge (TE) as pressure energy is converted to mechanical energy inside turbine runner Figure (4.25) and Figure (4.26), High pressure is exerted on the suction side of the turbine.It can be seen that the flow is accelerated in the runner resulting in a pressure drop.

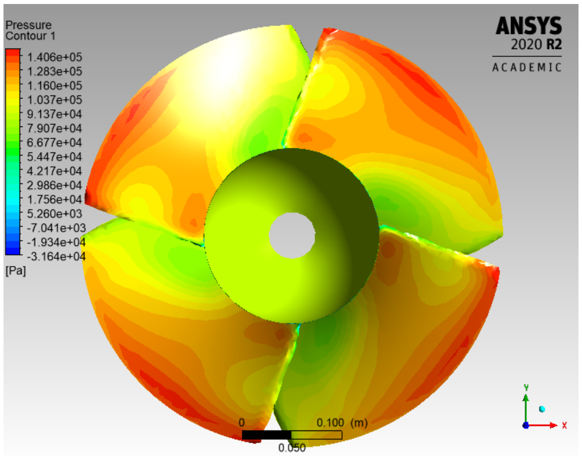


Figure 4.25: Axial view of the pressure distribution on runner

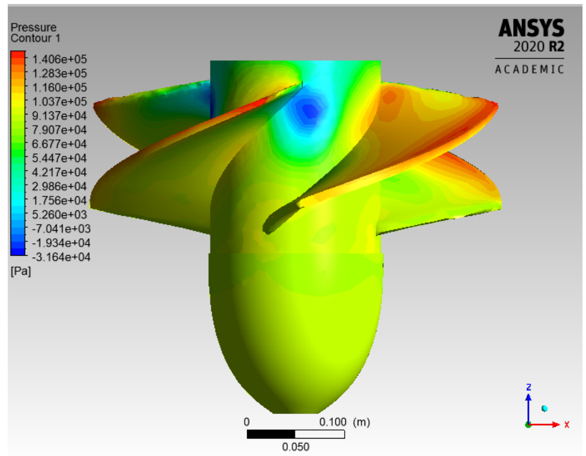


Figure 4.26: Vertical view of the pressure distribution on runner

4.7.3 Turbulence kinetic energy

Figure (4.27) shows the graph plots of the normalized turbulent kinetic energy distribution along the blade passage to the draft tube. It can be seen from the contour plots of turbulent kinetic energy that the turbulence is stronger on the blade suction side due to the presence of higher momentum fluid and it weakens whenever it goes towards the water outlet.

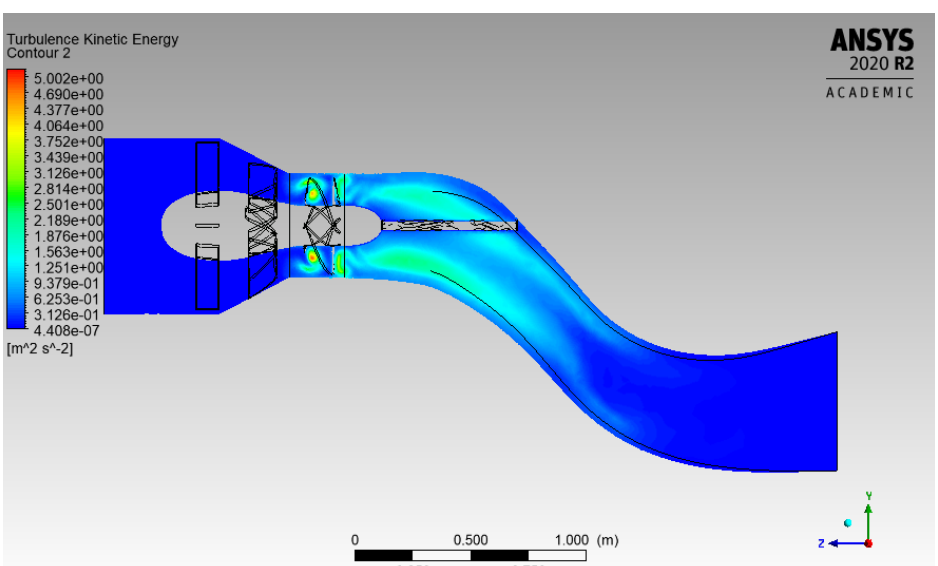


Figure 4.27: Distribution of the turbulence kinetic energy

4.7.4 vortex

Figure (4.28) shows the vortex regions at the S type Kaplan turbine system, where we note that the intensity of the vortex is greatest at the region of rotation near of the runner in which the flow revolves around an axis of rotation, and decreases in intensity as the fluid heads to the outlet.

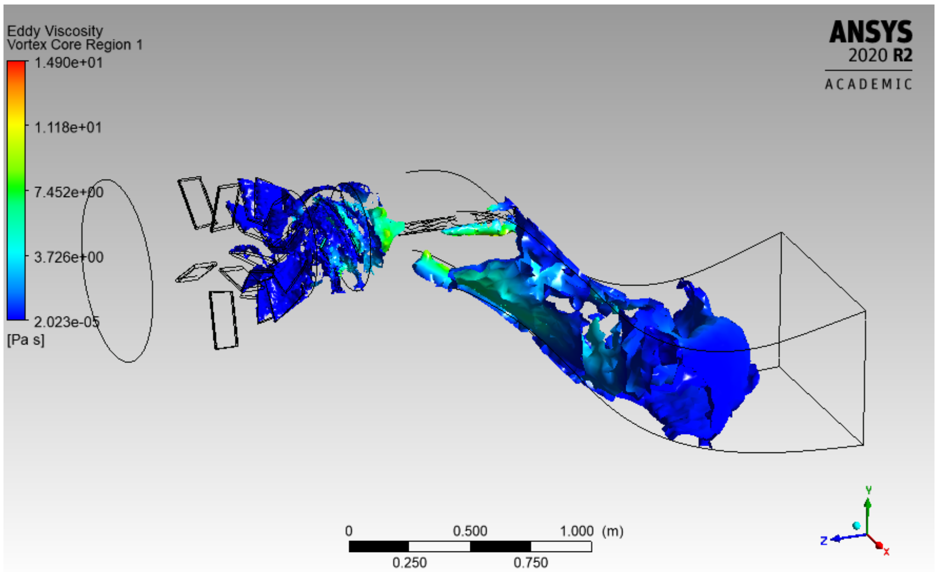


Figure 4.28: Vortex region of the S Kaplan turbine system

4.8 Conclusion

This study was based on the steady state flow analyses. For numerical analysis, three-dimensional modelling of the Kaplan turbine was performed from the drawing and scanning to the boundary conditions data.

The result of the calculations by means of the developed inverse method confirms the ability of that method to design process of hydraulic turbine of Kaplan type. The turbine runner shape designed using the newly developed method that used in real turbines projects.

Computer programs allow an accurate and in-depth understanding of the various phenomena that enable the achievement of three dimensional simulations and optimization of various types of turbines that help in developing ideal designs to obtain the best feedback at the lowest price.

CONCLUSION

THE purpose of this work was to contribute to improved methods of utilizing wastewater to produce electric energy, by proposing and designing a turbine model in order to generate significant electrical energy in order to feed part of the wastewater treatment plant for the city of Biskra, Taking into account both economic and environmental impacts.

In the current context, the demand for energy is likely to increase, especially electrical energy that is produced by traditional methods where the problem is that these sources are polluting sources of the environment. This work includes developing better strategies to obtain clean, free, and unending energy and to manage available resources to reduce excessive consumption of traditional energy and thus reduce costs and adverse impacts on the environment.

In this work we have studied the turbine model through the roads theoretical and numerical modelling. This work was mainly done through "Ansys" simulation program. Where three-dimensional simulation enables the ability to model and simulate all types of flows through the turbines and study all kinds of variables, from velocity, pressure and different acting forces.

Our goal is to design and optimize a turbine model with all the necessary structures in addition to manufacturing materials by conducting a study on material resistance and computer simulations. And in order to obtain the best yield, and also to study the behaviour and changes of the turbine work in the event of changes in working conditions and the flow of wastewater.

Finally, future technological developments must be watched: new turbines Hydraulic systems adapted to various small and variable water sources can achieve considerable energy gain, making hydraulic energy recovery from wastewater more common. So wastewater offers an interesting potential, not just economic, But also by producing clean local energy Without impacts on the environment.

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