—-------------------------------------Entry to the UK Junior Water Prize 2022 —--------------------------------

Investigating optimum conditions to obtain potable water through piezoelectricity in fluvial systems

This is the report dedicated for the 2022 UK Junior Water Prize.

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Preliminary Matters

Abstract:

Water contamination due to industrialisation poses great challenges to the potability of water, especially in countries with a lack of accessible energy and processes for water treatments. Piezoelectric materials are able to convert changing mechanical stress to electricity. By modelling the fluvial and treatment systems, this research has examined the effectiveness of different structures in producing voltages. Comparisons between the horizontal design, vertical design and the 'droplets' design have been made by analysing the graphs of voltages produced, leading to a conclusion that the inherent instability of water jet and formations of droplets can help to maximise power generation at high frequency and a critical distance between the exit of water and the piezoelectric material. This aids the overall design for an accessible piezoelectric water treatment system that can be adopted for citizens and government agencies with further potentials including the investigation of the optimum frequency for its function.

Table of content:

Key words:
Water treatment, potable water, filtration, piezoelectric water treatment system, piezoelectric effect, optimum conditions, frequency, critical distance, Plateau-Rayleigh instability, Young-Laplace equation, Weber number, droplet formation, perturbations

Abbreviations and acronyms:

NICs - Newly Industrialised Countries

PWTS - Piezoelectric Water Treatment System, a system to obtain potable water using piezoelectric materials

UNICEF - United Nations Children's Fund

UV - Ultraviolet

Acknowledgement:
We acknowledge the support from Ms Sophie Cavanagh (Headteacher of The Kingston Academy), Mr Neil Collins (Head of Geography in The Kingston Academy), Dr Vimal Gopee (Head of Physics in The Kingston Academy), Mr Edward Turk (Teacher of Physics in The Kingston Academy) in providing guidance and equipments for our researches.

Short Biography:

Yuquan Zhou - As an environmentalist, I want to use my passion for sciences to contribute to solving the environmental and social challenges (such as drinkable water scarcity) in the world. I would like to study Natural Science in university and use my research in the future to help society to develop more advanced and useful technologies to improve people's living standards to alleviate sufferings caused by humanitarian and natural crises.

Jason Cho - There are so many problems in this world. I want to dedicate my life to making an impact and solving a lot of these problems. I would like to study Computer Science in university and create a second world (virtual reality) that is indistinguishable from the real world (like the Matrix). The virtual world will be free of all these problems such as poverty (as we would have an infinite amount of resources), and while people are living in the virtual world, I will be addressing environmental problems in the real world.

Section 1 - Introduction

1.1 Status quo and current challenges

The world, especially NICs with areas of extreme inequalities, has experienced rapid industrialisation which poses considerable challenges to the water quality of many areas due to insufficient or unregulated waste disposal systems. This has entailed problems including potable water scarcity as many sources of water are contaminated with harmful microorganisms and organic wastes that are toxic to the human body. According to UNICEF, 2.2 billion people around the world do not have safely managed drinking water services [1] and unsafe water sources are responsible for 1.2 million deaths per year. It is also found that this is particularly detrimental to the more economically deprived 'low-income countries' where 6% of deaths are due to unsafe water sources [2]. One of the big issues for the latter is the lack of sufficient accessible and inexpensive energy generation to facilitate a provision of potable water without harming the local ecosystem, which may be important to sustain the primary industries [3], and many other services related to hygiene and sanitation. For example, energy is required for desalination, pumping water from fluvial or coastal systems, or using UV (ultraviolet) light to sterilise water sources as a part of the process to obtain potable water [4].

Turbines and dams are commonly used in water systems to convert kinetic energy into electrical energy. These have been employed by numerous countries, some with success, some with drastic negative consequences. Not only can these technologies have high initial costs, they can also severely harm the ecosystem by reducing nutrients content in rivers, increasing the rate of erosion downstream, reducing water habitats and disrupting lifestyles of animals in the sources of water (e.g. migration routes) [5].

1.2 Our initiative

Discovered by Jaques and Pierre Curie [6], piezoelectric materials, with an asymmetrical unit cell, generate electricity by the displacement of ions when forces are applied. Both contraction and expansion are needed to create potential difference continuously [6]. This property of piezoelectric materials has been exploited in sensors, inkjet printers, microbalances etc [7]. Recent research has highlighted that many lead-free piezoelectric materials including barium titanate oxide ($BaTiO_3$) and potassium bismuth titanate [8] can have extremely powerful properties. Rapid and promising developments has been made in discovering and synthesising new organic and even more biocompatible piezoelectric materials [9]. The use of piezoelectricity will not only supplement the energy generation constantly to purify water and for many other services but also minimise the negative environmental impacts many other initiatives have struggled to prevent. We are researching on finding the optimal structure and location for electrical generation using piezoelectric materials and their compatibility with water treatment systems, leading to a conclusion regarding their potential uses for different stakeholders on the issue of potability of water.

Section 2 - Materials and methods

The overall purpose of the investigation is to find the most suitable way to generate electrical energy and to propose the best design of the piezoelectric water treatment system (PWTS). Piezoelectric effect converts mechanical stress into electrical energy by the generation of electric charge and hence a voltage. As the electrical resistance of the piezoelectric material and the wires in the circuit is the same, in a given time, the energy generated is directly proportional to the voltage as demonstrated by the equation:

$E = Pt = \frac{V^2}{R} \cdot t$ where E, P, t, V, R are energy, power, time, voltage and resistance respectively (1)

Our investigation is constituent of two main tests in order to test the best way to locate piezoelectric materials in the PWTS. Test 1 involves testing whether the voltage will increase with multiple piezoelectric crystals in series and parallel structure. Test 2 is constituent of three sub-tests - Test 2.1 Horizontal design; Test 2.2 Vertical design; Test 2.3 'Droplets' design. The scenario that each test is attempting to model is summarised in **Table a** below:

Test number	**It is used to imitate…**	**Location of the piezoelectric material in the design**
Test 2.1	Flow of water through a river channel	Vertically placed (i.e. perpendicular to the direction of flow of water)
Test 2.2	Flow of water downwards in a pipe in the treatment plant	Horizontally placed (i.e. perpendicular to the direction of flow of water)
Test 2.3	Flow of water after the filtration process	Horizontally placed (i.e. perpendicular to the direction of flow of water)

Table a Modelling using Test 2.1, 2.2, 2.3

2.1 Materials

Below provides a list of the materials we used for the investigation:

- Brass piezoelectric discs - used as an example of piezoelectric materials
- PicoScope 2204A USB Oscilloscope (from school) - used to measure voltage produced by the piezoelectric materials by connecting them using insulated wires
- Laptop - used to connect to the oscilloscope to display graphs of voltages against time
- Insulated wires - used to connect piezoelectric discs and the oscilloscope
- Garden hose pipe, shower hose and drinking tap - used as water source to model different river conditions and the force of water the piezoelectric material will receive in Test 2.1 and Test 2.2
- Water bottles - used to model the river channel and pipelines
- Filter - used to create water droplets in Test 2.3
- Ruler - used to measure distance and height of water column

- 250ml beaker - used to measure the volume of water and calculate the rate of flow
- Stopwatch - used to measure time and to calculate the rate of flow

For the repeatability of the investigation the detailed specification of the piezoelectric material is also listed:

Specification of the brass piezoelectric discs

- *Material: Brass*
- *Diameter: 10mm*
- *Thickness: 0.3mm*
- *Resonant frequency: 3.0~5.0 ± 0.5 kHz*
- *Resonant impedance: 300 Ohms (max)*

2,2 Experimental procedures:

The oscilloscope is connected to the laptop which displays the graphs of voltages against time.To obtain the voltage data from the oscilloscope, the graph is stored in the form of .psdata after each test. Pictures are also taken to store the graphs in the form of .jpg file.

→ 2.2.1. Test 1 - Series and Parallel

1. Two standard electric circuits are being set up: one in series and one in parallel.
2. In each circuit, two piezoelectric crystals are connected together
3. In each circuit, press one piezoelectric crystal with a constant force 3 times with a time interval of 1 second between each force applied.
4. Then in each circuit, press two piezoelectric crystals at the same, each with the same force, 3 times with a time interval of 1 second between each force applied.
5. Repeat the test 4 times for both series and parallel circuit.

→ 2.2.2. Test 2.1 - Horizontal design

Figure 1.1 Test 2.1 apparatus

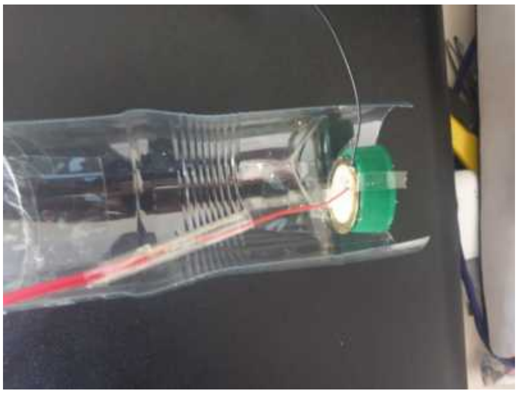


Figure 1.2 Test 2.1 apparatus

1. An empty semi-cylindrical trough (e.g. using water bottles) is used to model the river channel.
2. A garden hose pipe is attached to one end of the trough and the piezoelectric disc is secured on the other end connected to the oscilloscope as shown in **Figure 1.1** and **Figure 1.2**
3. The rate of water flow can be measured by calculating the time it takes for the hose pipe to fill a 250ml beaker using a stopwatch. This should be done 3 times to calculate a mean.

$$Rate = \frac{Volume}{Time} = \frac{250}{Time} \quad (2)$$

   This is calculated as this needs to be kept the same for further research on the horizontal design if it is a suitable design.
4. Turn on the hose pipe; observe and record the voltage pattern on the oscilloscope. Make sure that the water is in laminar flow.

THIS DESIGN IS NOT BEING INVESTIGATED FURTHER as explained in the result section.

→ 2.2.3. Test 2.2 - Vertical design

Figure 2.1 Test 2.2 apparatus

Figure 2.2 Test 2.2 apparatus

Figure 2.3 Test 2.2 apparatus

1. An empty semi-cylindrical trough (e.g. using water bottles) is used to model a horizontal pipeline.
2. At one end a water bottle, another water bottle modelling a vertical pipeline is connected to the trough and placed vertically downwards as shown in **Figure 2.1**, **Figure 2.2**, **Figure 2.3**. The piezoelectric material is secured at a relatively short distance to the nozzle of the water bottle where the water exits and connected to the oscilloscope.
3. *See Test 2.1, Step 3 - In this test, a shower hose is used instead of a garden hose pipe.*
4. *See Test 2.1, Step 4 - In this test, a shower hose is used instead of a garden hose pipe.*

THIS DESIGN IS BEING INVESTIGATED FURTHER using the methods below:

5. Use a ruler to adjust the distance from the nozzle to the piezoelectric material to 10cm and measure the voltage over a certain period of time.

6. Repeat step 5 for distances of 20cm and 30cm. Make sure that the water is always in laminar flow.

→ 2.2.4. Test 2.3 - 'Droplets' design

Figure 3 Test 2.3 apparatus

1. Connect the piezoelectric material to the oscilloscope, directly under locations of droplet formations as shown in **Figure 3**.
2. Test the feasibility of the idea by observing the voltage when droplets are being created by pipette and hit the piezoelectric material.

THIS DESIGN IS BEING INVESTIGATED FURTHER using the methods below:

Investigating the effect of changing frequencies of droplets

3. Observe and record the voltage pattern on the oscilloscope when the frequencies of the droplets are 0.5Hz, 1.0Hz, 1.5Hz, 2.0Hz, 2.5Hz respectively. The distance between the tap where the water exits and the piezoelectric material should be the same for all the tests in this step. Make sure that water droplets are able to form before the jet of water hits the piezoelectric material.

Investigating the effect of changing hydraulic diameter of the jet of water

4. Observe and record the voltage pattern on an oscilloscope when the water column diameter is 1mm, 1.5mm, 2mm, 2.5mm. The distance between the tap where the water exits and the piezoelectric material should be the same for all the tests in this step. Make sure that water droplets are able to form before the jet of water hits the piezoelectric material.

Section 3 - Results

Our results are displaced as a graph of voltage (y-axis) against time (x-axis). The scale of the axis varies with different experiments.

3.1 Results and analysis for Test 1

Note that the result for Test 1 doesn't require the axis to be shown as we are only trying to find whether there is a proportional relationship between the number of piezoelectric crystals in series/parallel and the voltage.

→ *Series*

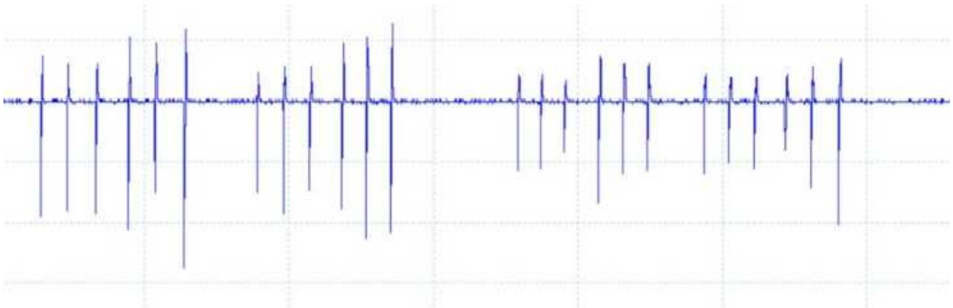


Figure 4 Test 1 results - Series

There are 4 trials of the experimental procedures as shown in **Figure 4**. On average, the voltage generated using 2 piezoelectric materials connected in series doubles that generated using only 1. This confirms Kirchhoff's 2nd law.

→ *Parallel*

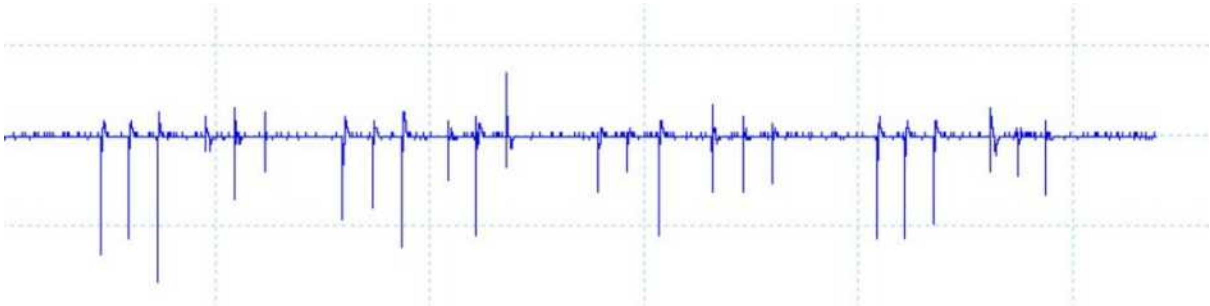


Figure 5 Test 1 result - Parallel

There are 4 trials of the experimental procedures as shown in **Figure 5**. On average, the voltage generated using 2 piezoelectric materials in parallel is the same, if not less, compared to that generated using only 1.

Overall, to maximise generation of voltage, a series circuit will be adopted within our design.

3.2 Results and analysis for Test 2.1

It is worth noting that this test is different from 'droplets' test because the water stays in the form of laminar flow and the stream of water hasn't been broken into droplets.

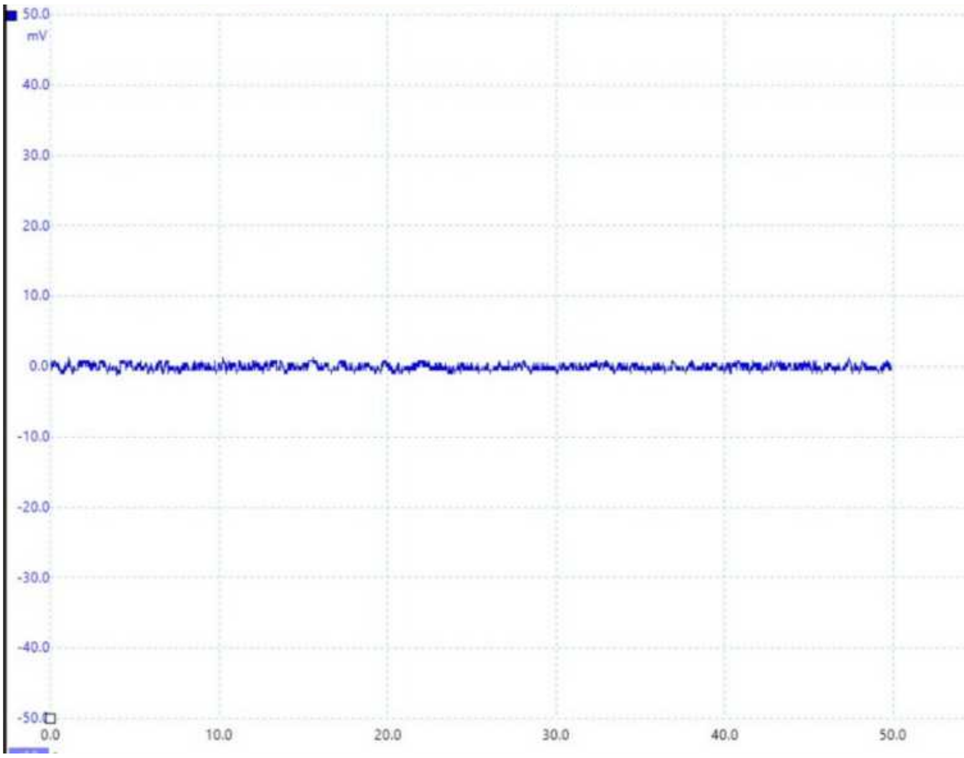


Figure 6 Test 2.1 result

Analysis:
It is shown, in **Figure 6**, that the voltage produced by water is negligible (less than 1mV) regardless of the force of water. As the laminar flow of water in the horizontal system is constant, it proves that such a design which exploits the constant stress of the fluvial system (i.e. one that doesn't provide a changing pressure upon the surface of the piezoelectric material) doesn't generate much electricity, hence not effective for the purpose of this research. This means that it doesn't need to be researched further, hence the value for the rate of flow of water in this test is not useful for the other part of the research.

<u>3.3 Results and analysis for Test 2.2</u>
It is worth noting that this test is different from 'droplets' test because the water stays in the form of laminar flow and the stream of water hasn't been broken into droplets.

It takes 3.90, 3.82, 3.96 seconds to fill the 250ml vessel. This is equivalent to a rate of flow of 64.2mls^{-1} and this will be a controlled variable throughout Test 2.2.

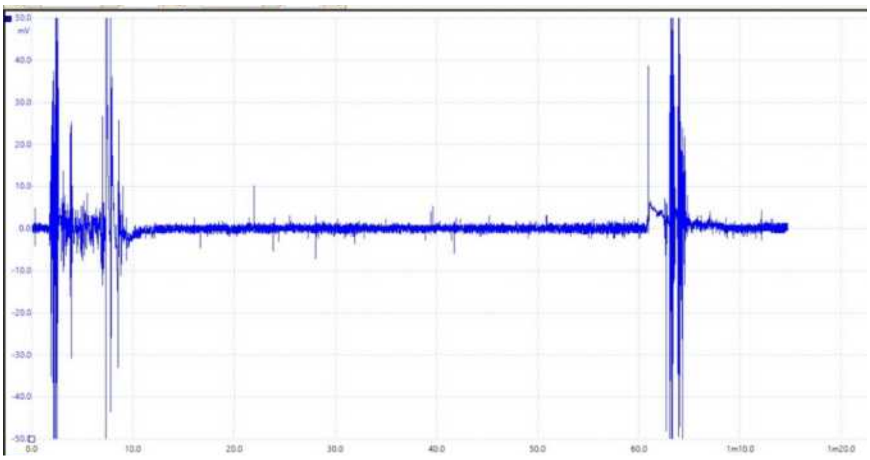


Figure 7 Test 2.2 result - 10cm

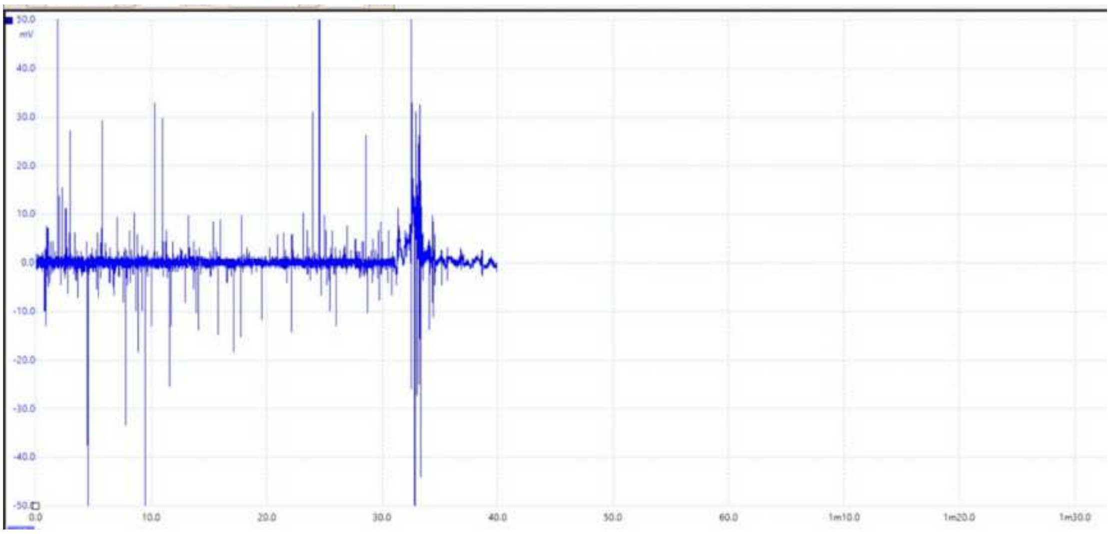


Figure 8 Test 2.2 result - 20cm

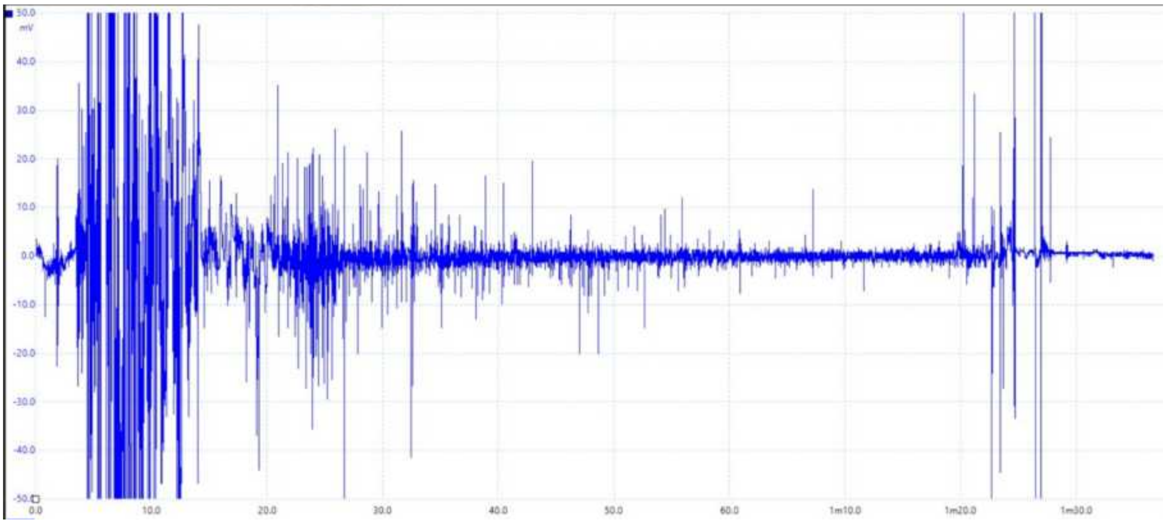


Figure 9 Test 2.2 result - 30cm

The time period from 10 to 60 seconds in **Figure 7** shows the result for the 10cm distance test in Test 2.2. The time period from 0 to 20 seconds in **Figure 8** shows the result for the 20cm distance test in Test 2.2. The time period from 30 seconds to 1minute 20 seconds in **Figure 9** shows the result for the 30cm distance test in Test 2.3. The larger voltages outside the time period are due to perturbations when setting up the apparatus for the investigation and can be ignored.

Analysis:

The voltage produced by the vertical design is much more prominent than the horizontal design in two ways. Firstly, the constantly alternating voltage is evaluated at ±2 mV which doubles that of the horizontal design. Also, there are 'irregular peaks' of voltages that reach a maximum of 50mV in the 20cm test. These irregularities are likely to be caused by the slightly changing orientation and vibration of the piezoelectric disc due to the slight instability of the water beam. This instability will be discussed further in *Section 3.4 and Section 4.2*.

Initially as the height increases, the voltage increases because the mechanical force is greater as water accelerates for a longer period of time and at the time of collision, the change in momentum is higher. However, there is a critical value at which if the height continues to increase while the water still stays in a complete stream of laminar flow, the voltage, hence power and energy generated, will be lower. This can be due to lack of changing pressure (as concluded by Test 2.1) due to the increased compression of the piezoelectric material but a lack of the release of the force. The critical value is different for different piezoelectric materials and it seems to be located at around 20cm for our material.

3.4 Results and analysis for Test 2.3

→ *Changing frequencies*

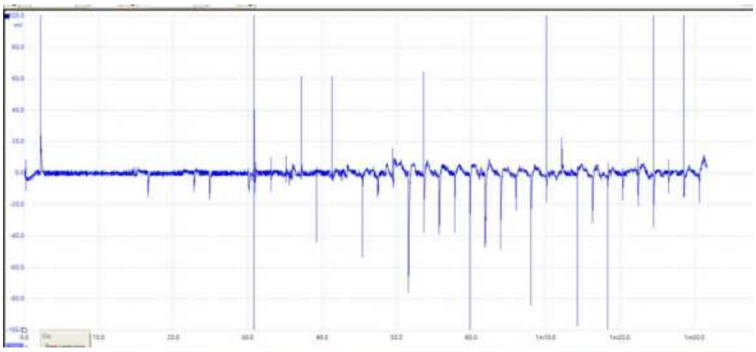


Figure 10 Test 2.3 result - 0.5Hz

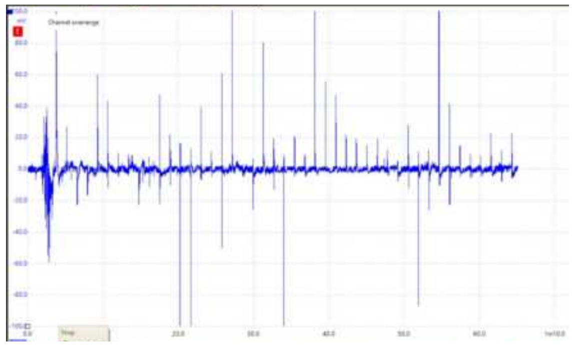


Figure 11 Test 2.3 result - 1.0Hz

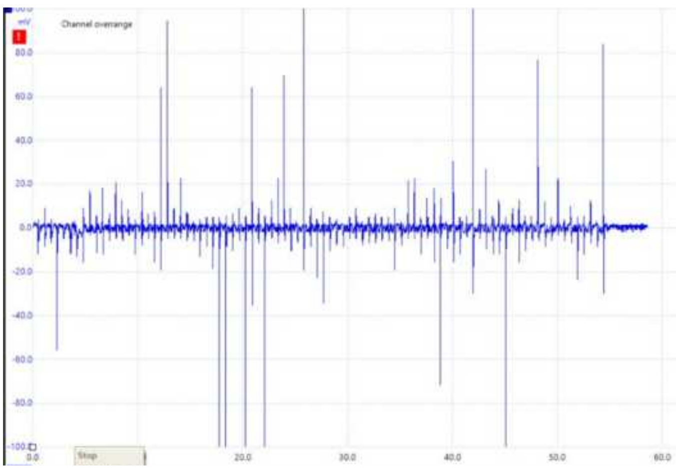


Figure 12 Test 2.3 result - 1.5Hz

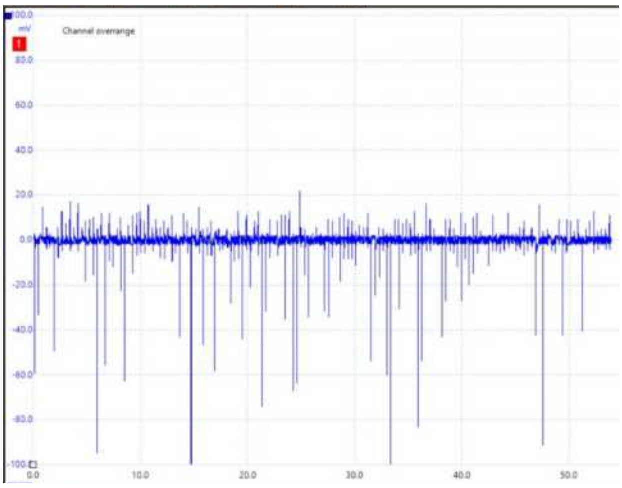


Figure 13 Test 2.3 result - 2.0Hz

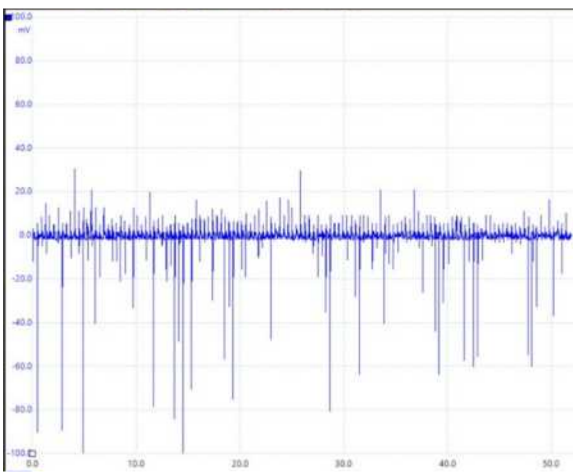


Figure 14 Test 2.3 result - 2.5Hz

Figure 10 - 0.5 Hz
Figure 11 - 1.0 Hz
Figure 12 - 1.5 Hz
Figure 13 - 2.0 Hz
Figure 14 - 2.5 Hz

Analysis:

The ‘droplets’ design is the best out of the three designs due to not only the higher voltage it can generate but also the predictability of the frequencies, hence electrical generation. There is a direct proportional relationship between the frequency and the number of peaks of voltages (ranging up to around 100mV), which is the highest achieved out of all the designs. This means the higher the frequency, the higher the amount of power and energy can be generated. Also, it is observed that the higher the frequency, the voltage is more ‘one-sided’ on the graph. We hypothesise that this is due to the fact that the initial distortion of the crystal structure is bigger in one direction than the other. This causes the damping effect to occur, reducing the energy before it recoils in the other direction.

→ *Changing hydraulic diameter*

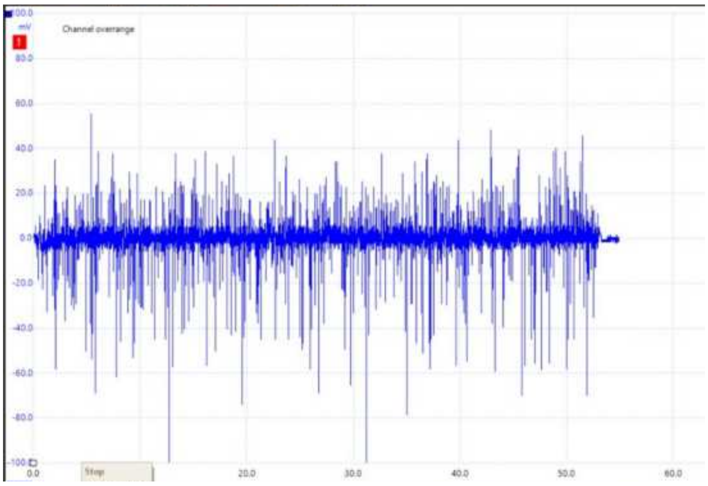


Figure 15 Test 2.3 result - 1mm

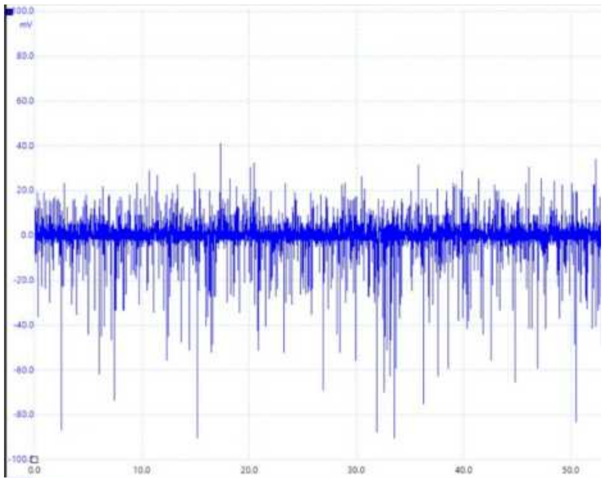


Figure 16 Test 2.3 result - 1.5mm

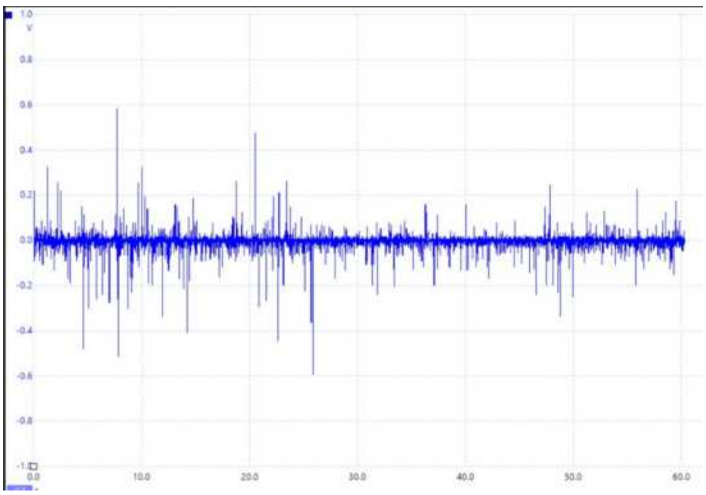


Figure 17.1 2.3 result - 2.0mm (1)

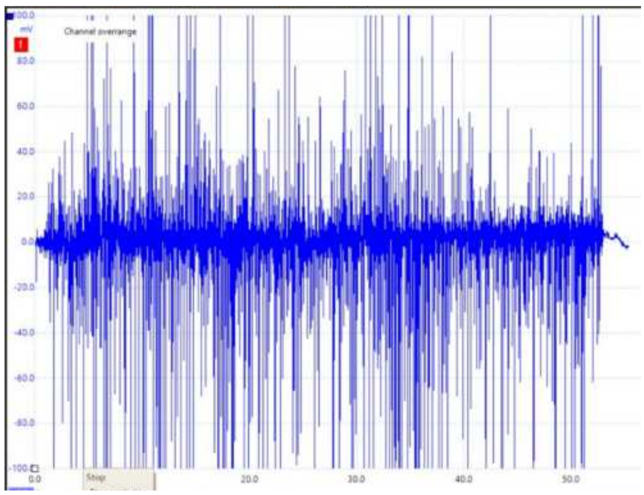
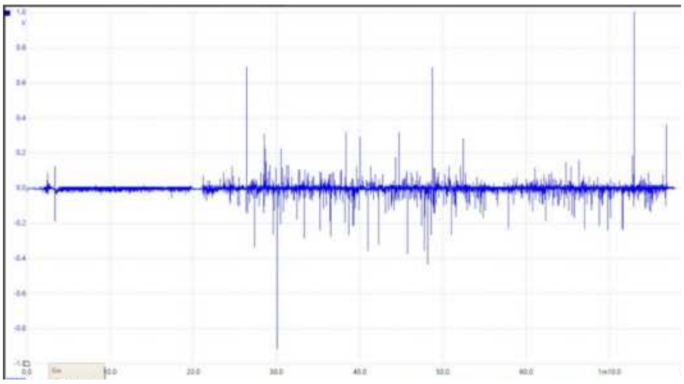


Figure 17.2 Test 2.3 result - 2.0mm (2)



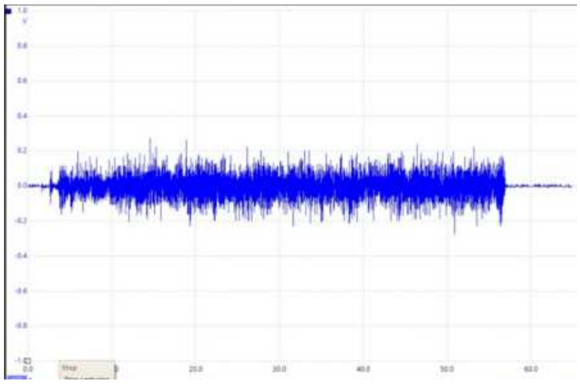


Figure 18 Test 2.3 result - 2.5mm **Figure 19** Test 2.3 result - 'Shower' mode

Figure 15 - 1mm
Figure 16 - 1.5mm
Figure 17.1, 17.2 - 2mm
Figure 18 - 2.5mm
Figure 19 - An interesting test using the 'shower' mode of the tap creating multiple jets of water with rapid droplet formations.

*Note that **Figure 17.2** is equivalent to **Figure 17.1** but with a smaller scale for comparison purposes with other tests in this report.*

Using dimensional analysis of the Plateau-Rayleigh instability, a relation between critical length (the length from which the droplet forms to the exit of water at the tap) and the fluid properties and be found:

$$\frac{L_{crit}}{R} \sim U\left(\frac{\rho R}{\gamma}\right)^{\frac{1}{2}} \tag{3}$$

where ρ, R, U, γ are density, column radius, jet stream velocity, surface tension respectively [10].

This shows as the column radius increases, the critical length increases as the density, jet stream velocity and surface tension are controlled to be constant. Hence by gradually increasing the column diameter (2R), we gradually increase the critical length and decrease the distance between the pinching point (the point at which the droplet forms) and the piezoelectric material as the distance between the latter and the exit of water from the tap is kept constant.

The frequency of all the tests are not quantified but are all much more than that in the 'changing frequency' test. The force is created by the formation of droplets due to Plateau-Rayleigh instability of which use will be further explored in *Section 4.2*.

Analysis:
This design is shown to be the most effective and consistent design because not only the number of peaks of constantly and 'irregularly' alternating voltages have increased due to an increased frequency in droplets (as concluded by the 'changing frequency' test), but the peak voltage has also drastically increased to a maximum of 1V (1000mV), which is 10 times greater than the maximum value obtained in any of the other tests. The constantly alternating voltages are evaluated at ±10mV, 5 times greater than the highest such value achieved previously.

A further result that is unexpectedly obtained is shown in **Figure 19** when the 'shower' mode of the tap is used to generate multiple jets of droplets with greater force and frequency. There is a 100mV constantly alternating voltage and there are multiple peaks that have achieved more than 200mV. However, the consistency of the voltage generated is much higher than most of tests in Test 2.3. This is likely due to the more regulated droplet pattern, resulting in a more regular alternating voltage.

3.5 Overall result summary

Our overall result for Test 2.1, 2.2, 2.3 (excluding the shower mode) is summarised in **Table b** below:

Test number	**Constantly alternating voltage**	**Irregular peaks of voltage**	**Conclusion**
Test 2.1	1mV	N/A	Constant stress will not produce sufficiently high voltages.
Test 2.2	2mV	50mV	Vibrations and changing orientations of the piezoelectric material can be exploited to generate electricity. There will also be optimum critical distance for the piezoelectric material to be placed away from the exit of water.
Test 2.3	10mV (Shower mode: 200mV)	1000mV (Shower mode: 300mV)	The **best design** with the highest potentials due to highest constantly alternating voltage and irregular peaks of voltage. Higher frequency with shorter distance between the critical pinching point for droplet formation and the piezoelectric material generates higher voltages.

Table b Overall results for Test 2.1, 2.2, 2.3

Note that more energy can be generated using piezoelectric materials that are more powerful than the ones used in this investigation but our research is attempting to find the optimum structure and design, not finding the best piezoelectric material. The latter is worth being investigated in future research.

Section 4- Discussion

4.1 Potentials of the design

Although lots of conclusion can be made on the effectiveness of different designs and structures and correlations have been found between different factors, there are still aspects that are worth researching and exploring in the future and hypotheses that need to be confirmed by further investigations including:

- Whether both sides of the piezoelectric materials can be utilised in future designs
- The resonant and optimum frequency of the droplets hitting the piezoelectric material to generate the highest amount of power and energy

- Critical/optimum distance for different piezoelectric materials in different PWTS to generate the highest amount of power and energy
- The best piezoelectric material to be used in water systems in terms of its power to generate electricity, toxicity and durability under stress and in water with different pH
- The potentials of the 'shower' mode can be investigated further by modelling the use of multiple jets of water with rapid droplet formation.

4.2 Wider social, scientific, technological context

The initiative has targeted the issues of potability of water in innovative ways by minimising external environmental damages and transportation costs to deliver energy, increasing flexibility of the location to place the piezoelectric material to supplement sustainable energy production and the controllability of electrical generation in a more localised system.

The discussion of Plateau-Rayleigh instability [11] is needed to demonstrate the controllability of the electrical generation using piezoelectricity. This basic concept behind the fluid dynamics of the instability of water beams and droplet formation is well understood by the scientific community. The varicose perturbations in the supply system are increased as the stream of water attempts to minimise its surface area to reduce surface tension due to its tendency to remain in the most thermodynamically stable state [10]. The areas of high pressure and low pressure can be deduced by the Young-Laplace equation [12]:

$$\Delta p = -\gamma\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \tag{4}$$

Where γ is the liquid surface tension, Δp is the pressure difference across the liquid surface and R_1 and R_2 are the principal radii of surface curvature.

As the displacement amplitude grows, the formation of droplets is initiated. The initial undulations can be created naturally or artificially and the rate of growth of instability can be altered by regulating the different conditions including the diameter of the cylindrical stream (R_0) and the wavenumber of the sinusoidal (k). In particular, the rate is the fastest if:

$$kR_0 \simeq 0.697 \qquad (5)[10]$$

Conditions to break up larger droplets into smaller ones are also well researched:

$$We = \frac{Drag\ Force}{Cohesion\ Force} = \frac{\rho v^2 l}{\sigma} \tag{6}$$

Where ρ, v, l, σ are density of the fluid, velocity, characteristic length (typically the droplet diameter) and surface tension respectively

If $We > 11$droplets are guaranteed to form [13].

This indicates that while constructing the actual PWTS, various conditions can be easily controlled using the 'Droplets' design with optimum conditions already or yet to be investigated. Furthermore, although only AC (alternating current) is generated using piezoelectric effect, a rectifier can be used in the circuit to convert AC to DC (direct current) in order for the charges to be stored in capacitors, supercapacitors or rechargeable batteries. As the flow of water and the formation of droplets are both constant and regulated, the charges will accumulate and services that require energy can be provided whenever needed by discharging the capacitors or the batteries. Any heating effect in the circuit due to current flow can be mitigated by the cooling effect of water itself. The system can also combine well with other ways of generating electricity if additional energy is needed to meet the demands of the tasks.

The flowchart below summarises the overall process involved in a PWTS:

Water droplets (which provide forces) → [piezoelectric material] →AC current and voltage in piezoelectric material → [rectifier] → DC current → [Capacitor/Rechargeable battery] → Energy discharged to treat water (e.g. UV light for sterilisation)
[...] - the mechanism that leads to the change

Recent researches on piezoelectricity (as mentioned in *Section 1 - Our initiative* section) have also seen promising prospects in the development of non-toxic and biocompatible piezoelectric materials [14] minimising the negative environmental impacts should PWTS cause any.

In the social context, this initiative can be used by local people, local or national agencies in countries with different levels of developments for various uses. One of the innovations and advantages of the design is that the use of piezoelectric material localises the energy production, especially for treatment of water. This means energy used to treat the water can be obtained from the water itself during the process of treatment, vastly reducing transportation of energy and resources as well as the damages to the ecological environment. The process itself is self-contained and can be regulated to achieve maximum voltage output for different structures of the design, making its location very flexible for the designer of the final product to operate different functions in the PWTS. Hence overall, the research has integrated solutions to both social and environmental issues regarding water treatments effectively.

The various uses for different stakeholders are summarised in **Table c** below. The electricity produced can be used for directly treating the water or to supplement energy for other services to relieve the challenges of obtaining drinkable water such as the transportation and distribution of water source and the construction of such systems. By making the design usable by public agencies and individuals, the research helps to publicise the potential solutions to raise awareness and alleviate the exposed problems of potable water scarcity.

Stakeholder	Main uses	Advantages of using PWTS
Local people	Smaller version of PWTS can be used at home or to obtain water from a water source such as a river.	● Portable ● Accessible and easy to use ● Sustainable and free after installation
Local agencies	PWTS can be designed to provide potable water for local people at sites such as river banks. This can contribute to a larger national system of PWTS.	● Accessible for many citizens ● Doesn't damage the local environment or ecosystem services ● Sustainable and free after installation
National Agencies	Piezoelectric material can be installed in various locations including under any filtration vessel or where droplets will collide with a surface to exert a force.	● Provide additional energy when needed ● Can be used in many places without harming the original design or purpose ● Doesn't damage the local environment or ecosystem services ● Sustainable and free after installation

Table c Uses of PWTS for different stakeholders

4.3 Others' researches

The potentials of the interactions between piezoelectric material and sources of water have been, to a certain extent, realised by the scientific community. Various uses of piezoelectricity have been explored in larger systems in nature and smaller artificial environments. Some researchers have analysed a cliff-mounted piezoelectric system to absorb energy from harmonic sea-waves [15]; some have modelled the use of piezoelectric transducers to harvest energy from raindrops [16]; others attempted to optimise parameters for a UV-LED water disinfection system with respects to costs of different components [17]. While these research have all exploited the mechanical stress water can provide, our research still offers a novel perspective on the uses of piezoelectricity as we have demonstrated the not only relations between various factors and the energy generated by piezoelectric materials in different designs but also the compatibility of piezoelectric materials in many different scenarios such as under filtration systems. This increases the compactness of the design and promotes the use of local resources to deal with local challenges. On the other hand, if demands are high, the use of the optimum design in our research can be adopted on a larger scale without damaging the ecological status of the environment.

4.4 Example use of our researches

Water treatment generally involves multiple steps including coagulation and flocculation, sedimentation, filtration, disinfection [18].The filtration process naturally produces jets of water downwards which can help to create droplets for the PWTS.

Using the results obtained from the investigation, the following design is proposed as an example that can optimise the generation of energy and to minimise the damage to the environment:

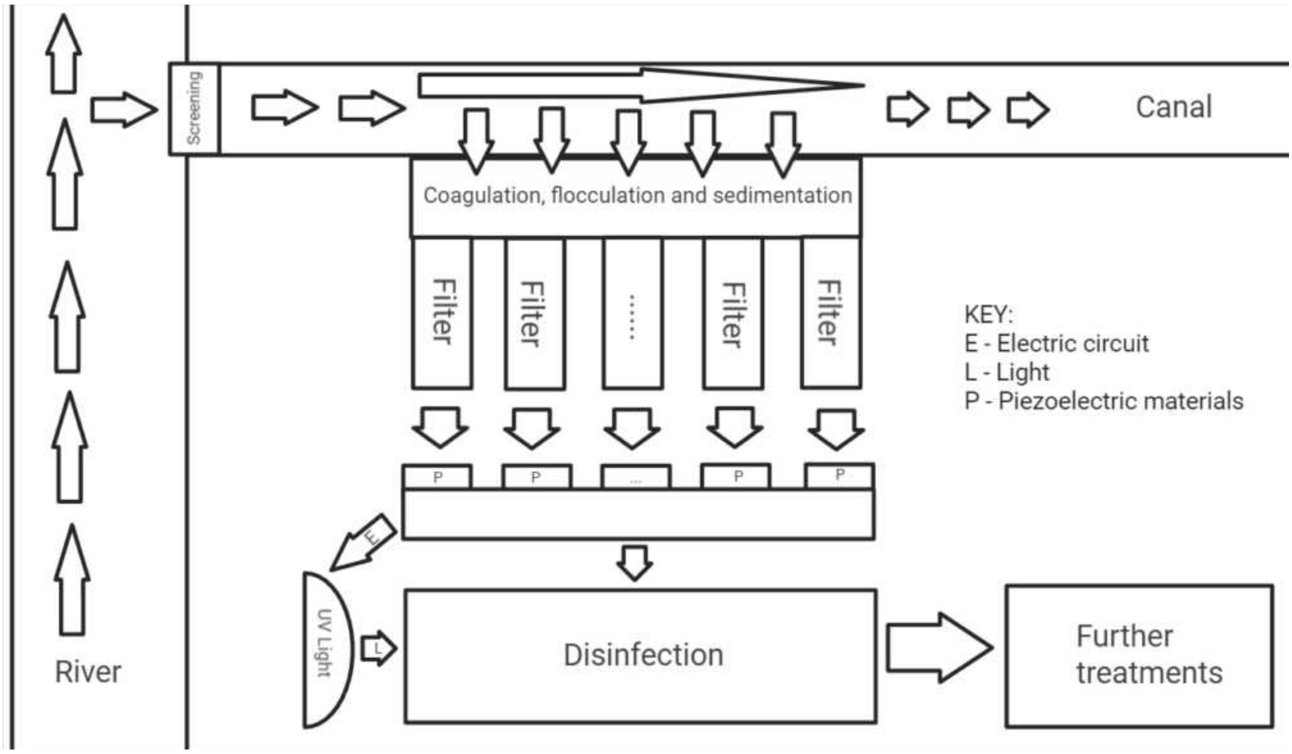


Figure 20 Example of a PWTS

1. Water flows naturally downstream in the river.
2. A canal leads some of the water away from the river after passing through screens to remove larger sediments and twigs. It may be the case that the screen can be closed or opened to allow water to flow to the canal only when it is needed. The electricity that may be required can be supplied by the circuits connected to the piezoelectric materials.
3. Some of the water in the canal goes to the water treatment plant (PWTS). The amount of the water that will continue to flow in the canal will vary in accordance to the local geography.
4. The water is initially treated using the traditional methods such as coagulation, flocculation and sedimentation.
5. Then the flow of water will be passed through multiple filters. Then the jets of water can form as the water exits and drips out of the filter. The filter size can be controlled to adjust the hydraulic diameter (to change the 'critical distance') and the frequency of the droplets to achieve optimum conditions to generate energy. *See Section 3 - Test 3.4 and Section 4.2 for more explanation.*
6. The electricity then can be generated using piezoelectric materials that are connected in series underneath the filter. This can be used in many ways including to power up UV light to sterilise the water in the process of disinfection.
7. The water then can be diverted away for further treatments.

Section 5 - Conclusions

We have demonstrated there is a need for a constantly changing pressure upon the piezoelectric material to generate electricity. In particular, the use of Plateau-Rayleigh instability to initiate water droplets formation in the 'Droplets' design is proven to be the best design for electrical energy production. At low frequencies in the range of 0.5-2.5Hz, power will be maximised by increasing frequency as it increases the number of peaks of alternating voltages although there seems to be a damping effect leading to low positive voltage but high negative voltage. It is also found that more power will be generated by reducing the distance between the pinching point where water droplets form and the piezoelectric materials. This can be achieved by increasing the hydraulic diameter of the water jet. Natural or artificial perturbations of the water jet can be used to optimise conditions including the height at which maximum voltages are reached due to the maximum amount of vibrations caused by the instability. The design is the best if multiple piezoelectric materials are connected in series with rectifiers and capacitors or rechargeable batteries to complete the circuit to store charges that can be discharged when needed. An example location of the piezoelectric material is immediately under a filter in the water treatment system. Although a lot of conclusions have been reached, further researches are desirable to provide insights in the optimum distance between the droplets and the piezoelectric material, the frequency of water droplets and the most suitable piezoelectric material, with low toxicity and high durability, to be used in water system.

Section 6 - References

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