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A Study on the Hydropower Energy Generation by Utilizing Domestic Water Supply

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ABSTRACT

Majority of households around the globe are connected to primary water supply grids that supply water for domestic use throughout the year. In many instances, the companies supplying water to these households maintain header pressure between the maximum and minimum as a guarantee for the water to reach the consumers. This paper is, therefore, aimed at investigating the potential of this pressure in driving turbines for power generation so that the energy could be stored in rechargeable batteries which can be utilized whenever needed. Two sets of experimental setups were developed with turbines arranged both in series and parallel. The experiments were conducted using three working pressures, such as 1.5, 3.2 and 5 bar. It was observed that the turbine mainly depends on the water flow rate, where the higher flow rate is achieved in working pressure of 5 bar which is 33 LPM and 6 Watt generated. The power produced was increased to 12 W with a slight pressure drop of 0.1 bar after the second turbine. However, the drop in pressure was observed to be slightly higher for the lower working pressure. The turbine cut-off pressure was 0.4 bar. Moreover, it was also evidenced that arranging the turbines in parallel has also resulted in an enhanced power generation.

1. Introduction

The demand for energy continues to increase significantly due to many domestic, agricultural, and industrial activities, which are rapidly growing to fulfil the needs of users [1-5]. Precisely, the annual rate of global principal energy dissipation is expected to increase by 1.6% between 2009 and 2030. As nearly 1.6 billion people are unable to access electricity worldwide, the energy variation arguably influences the global environmental feasibility, thus attracting the need for uncomplicated and equitable access to energy amenities [6]. In this regard, hydropower is among the technology alternatives to precipitate and provide electricity to rural and secluded routines with nil emission to cover this gap. Tian *et al.,* [7] stated that hydropower plants remain among the most significant sources of renewable energy.

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Hydropower has supplied electricity to systems of central power for civilization development for centuries thus achieving high levels of technological maturity. However, most plants adapted decades ago are capable to function in different environment as opposed to those compelled to them currently. Therefore, modern hydropower plants have a key challenge of enhancing their flexibility drastically by providing advanced system services and storage capacities that attract further development to support the integration of renewable energy variables [8].

Hydropower is generated from water through a combination of head and flow [9]. Water is directed to a pipeline to increase the pressure rate termed as the flow whereby the pipeline sends the water into a vertical drop, the head, creating pressure on bottom end. The intake is ordinarily the hydro system's peak point within which water is transferred from the stream to the pipeline feeding the turbines. This pressurized water emerging from the bottom end of the pipeline produces a force worth driving turbines with more flow and head producing more power. Notably, the generation of electricity is merely converting one form of power to another whereby the turbines transform the power of water to a rotational power on its shafts and thus converted to electrical power by the generator [10,11]. Hydropower holds a great prospective to lessen emissions of greenhouses and reliance on fossil fuels, mitigating climate change [12]. Remarkably, gas discharges from energy creation in greenhouses accounted for 29% of all discharges worldwide in 2012 [13]. In this regard, hydropower has an aptitude to ameliorate the people life quality by eradicating harmful emissions that affect negatively the human health and removing the need to collect firewood [14].

Many countries acknowledge that hydropower is almost carbon neutral, cost-competitive, and well-advanced source of energy. For instance, hydropower is a significant sector of Austrian energy system generating roughly 65.7% of the national electricity [15]. Hydropower provides substantial contributions to ensure sustained energy supply, realize climate change intentions, and establish manageable energy supply system to many countries worldwide. In addition, Bilgili *et al.,* [16] state hydropower supplies over and above 16.6% of entire global electricity to more than 160 nations worldwide. In Oman, power generation facilities rely heavily on non-renewable fossil fuels, which have attracted serious concerns for Oman to seek alternative sources of energy that are renewable, locally obtainable, and environmentally amiable [17].

Unfortunately, large hydropower plants demand huge deforestation, thus prone to catastrophic consequences such as critical ecosystem destruction, which can pose the risk of floods [18]. In addition, Guiamel and Lee [13] argue that hydropower developments alleviate persistent floods in level and low-lying downriver localities. Nevertheless, small hydropower plants do not attract large deforestation, thus a reliable alternative. They are power distribution compatible, which possesses outstanding regulation and volume element with lessened fluctuation ratio compared to the solar and wind [19]. Therefore, the need for alternative sources has forced a shift to hydropower renewable energy source usage, and this is becoming more pronounced and ultimately the expected trend is anticipated in the nearest future.

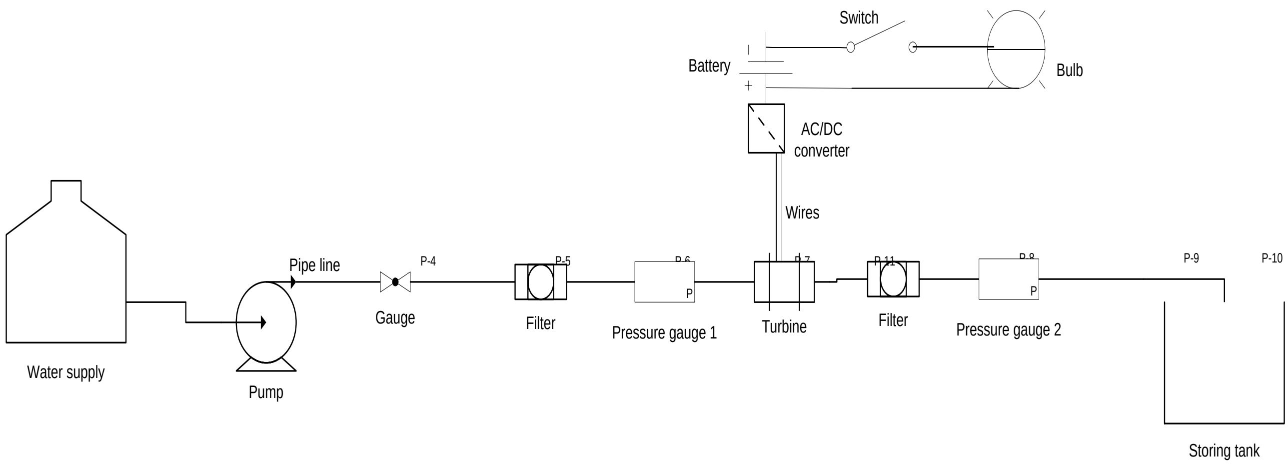
Many countries are committed to utilizing renewable energy sources, including water supply companies. There is indeed huge potential for recovering sustainable energy from the water cycle, and the major types of energy in water include thermal, organic, and other energies like kinetic energy, energy from osmotic values, and high pressure [20]. Hydropower installations can be used for generating electricity from the potential energy of falling water. However, it is essential to note that the water used for hydropower generation can still be utilized for other purposes such as domestic utilization, irrigation, and industrial processes, making it a multipurpose project [21]. Hydropower is considered mature and cost competitive that performs a strategic significant function of the current era electricity mix [22]. It is no doubt that countries continue to identify hydropower to be the key to satisfying the current growing demand for energy. Most countries especially in Africa such as Ethiopia have decided to develop huge hydropower projects on their major river basins that are not only considered a country's huge potential but also the additional economic, social, and environmental benefits the multi-purpose hydropower projects bring on board [23]. These advantages and the growing population can induce governments to utilize household water supplies to generate the renewable energy through hydropower systems. Furthermore, hydropower creates minimal greenhouse gases and the least costly approach to storing large amounts of electricity [24].

Ozcelik [25] argues that hydropower systems are a reliable source of electricity production and at the same time their water serving the needs of the population. This means that the household water supply systems might be a viable untapped avenue to adding their share in addressing energy demands while conserving the environment. The challenge remains where to install the systems to generate hydropower in water supply lines with researchers arguing that the most convenient locations is before the water treatment and distribution network [26]. Nevertheless, the in-pipe water to wire power system is an interesting integration of renewable resources as it possesses to harness clean energy from excess head pressure in domestic water pipelines [27]. This approach has shown abilities to perform along a wide range of head and flow conditions. It is a micro hydropower system that could be deployed in energy-intensive industries and agricultural irrigation schemes due to its provision of consistent amount of clean and continuous energy as well as helping in pipelines management [28].

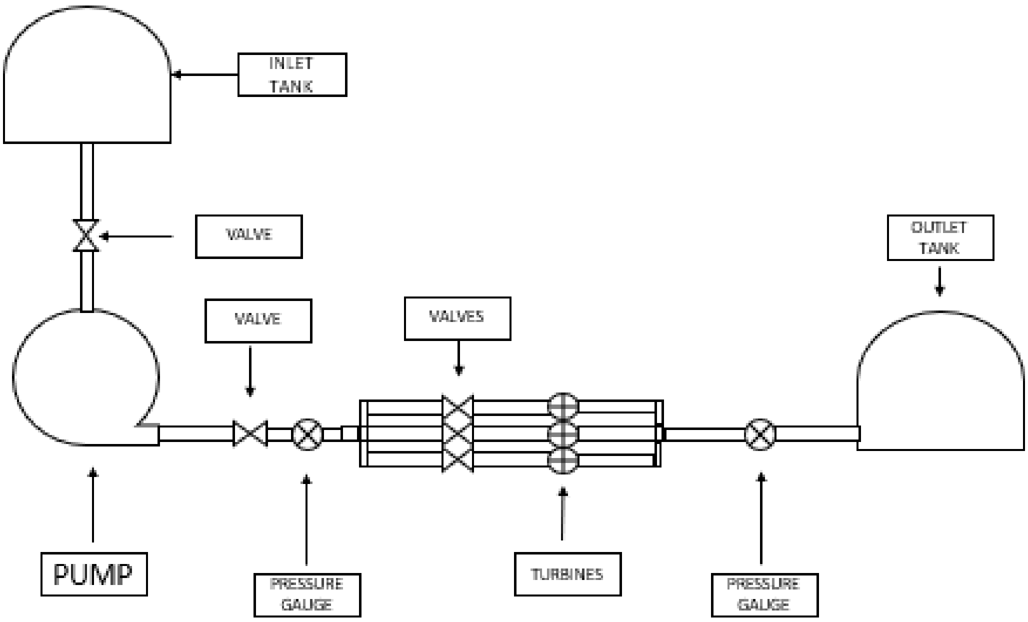
Majority of households around the globe are connected to primary water supply grids that supply water for domestic use throughout the year. The companies supplying water to these households maintain header pressure between the maximum and minimum as a guarantee of reaching water to the consumers [29]. In this regard, the higher pressure is capable of driving turbines connected to the power generations. The objective of this paper is, therefore, to investigate the potential of this pressure in driving turbines for power generation. The renewable energy generated by these systems can be utilized in powering some utilities in houses depending on the availability of water pressure rate. This becomes a sustainable source of renewable energy capable of addressing the challenge of growing energy demand coming from the rising household consumption because of the rising standards of living worldwide.

2. Experimental Setup and Techniques

The standard of the pressure that reaches houses is between 1.5 bar and 5 bar through a half inch water pipe. Pump was used to replicate the pressure of the domestic water supply. As a result, three different pump pressures giving different flowrates were used. A half inch water pipe was connected to the pump and a small turbine. The turbine would not interrupt the flow of water and it was connected to a generator, and then to a 12V rechargeable battery. Pressure gauges were installed before and after the turbine to measure the pressure. A filter inside the pipe was applied before and after the turbine for the safety purpose and to ensure that the water would reach the house tank for the case of system failure. Figure 1 shows replication of the real system of water for the case of turbines arranged in series. A gauge was then placed after the water pump to adjust and open the availability of water, while maintaining the same pressure, but the flow rate would be affected. A turbine was placed and connected through wires to the AC/DC converter as the turbine used gives AC power, and the power needed to charge up a battery is DC power. A 12V rechargeable battery and a switch is placed between the battery and the LED light, to use the energy stored when needed only. Another filter is placed after the turbine for the safety of the system and water stored for the consumers for the case of any damage happening to the turbine. Another pressure gauge is placed after the turbine to check if there would be any losses.



(a)



(b)

Fig. 1. Experimental setup – (a) Case 1 and (b) Case 2

In the first set of experiment, a 5-bar water pressure was used to rotate the turbine. A multimeter was used to measure the voltage and current. For each working pressure, five flow tests were conducted by using the water valve in five differentiate angles. Another analysis involves checking the time needed to charge up the battery using 5 bar water pressure, including the battery life. In the second and third set of experiments the minimum working pressure of 1.5 bar and average of 3.2 bar were tested. In the fourth set of experiment adding more than one turbine in the system was investigated. The cut off pressure of the turbine, which shows the pressure of not operating to generate power, was also investigated. The effects of arranging turbines in parallel were also investigated in this study.

3. Results and Discussion

In the first three sets of experiments, the procedure is repeated but with different working pressure in each one, and with the use of one turbine. In the fourth, another turbine is added to the system that makes a total of two turbines arranged in series. The latter is to figure out the cut of pressure of the turbine.

3.1 Effects of Flow Rate on the Energy Production When the Working Pressure was 5 Bar

Figure 2 depicts the flow rate versus the angle of valve for a working pressure of 5 bar. There was a gradual increase in the flow rate of the water as the angle of valve in the pump increased. It can be seen that on the angle of 15°, the flow rate of the water at that point was 6 LPM. As the angle of valve got increased such as for the angle of 65°, the water flow rate also increased to 23 LPM, showing a proportional relationship. Moreover, the maximum flow rate that can be obtained in a half inch water pipe for a 5 bar was 33 LPM. For the working pressure of 5 bar, the pressure reading after the turbine was 5 bar, with no drop in pressure.

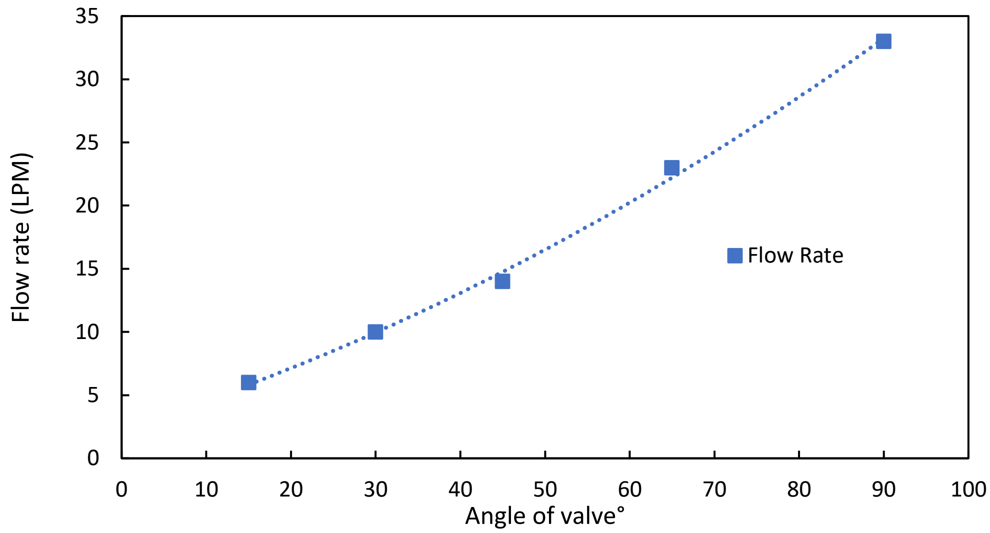


Fig. 2. Flow rate vs Angle of valve in 5 bar working pressure

3.2 Power Generation Versus Flow Rate for a Working Pressure of 5 Bar

Figure 3 shows a proportional relationship between flow rate and volt on a working pressure of 5 bar. It is determined that as the water flow rate increases, the volt gained also rises. It can be seen that on the point of 10 LPM of water flow rate, the voltage gained at that point is 12 V. And as the water flow rate increases such as for 23 LPM of flow rate, the voltage gained also rises, with a reading of 28 V. In addition, for a 5-bar working pressure, and through a half inch water pipe, the maximum voltage that could be gained is 40 V via a water flow rate of 33 LPM.

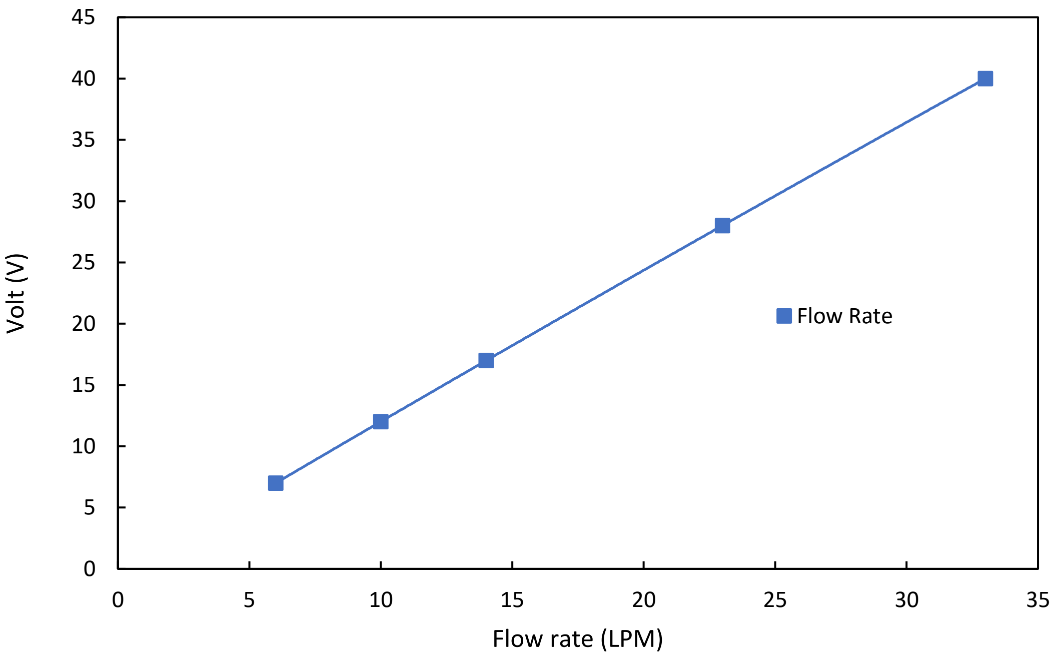


Fig. 3. Flow rate vs Volt for 5 bar working pressure

Figure 4 shows the relationship between flow rate and current on a working pressure of 5 bar. It was observed that for a 6 LPM of water flow rate the current was 0.15 A. As the flow rate increases, for example for 14 LPM, the current remained constant with reading of 0.15 A. This was due to a series connection, and the change in current do not occur due to the resistor.

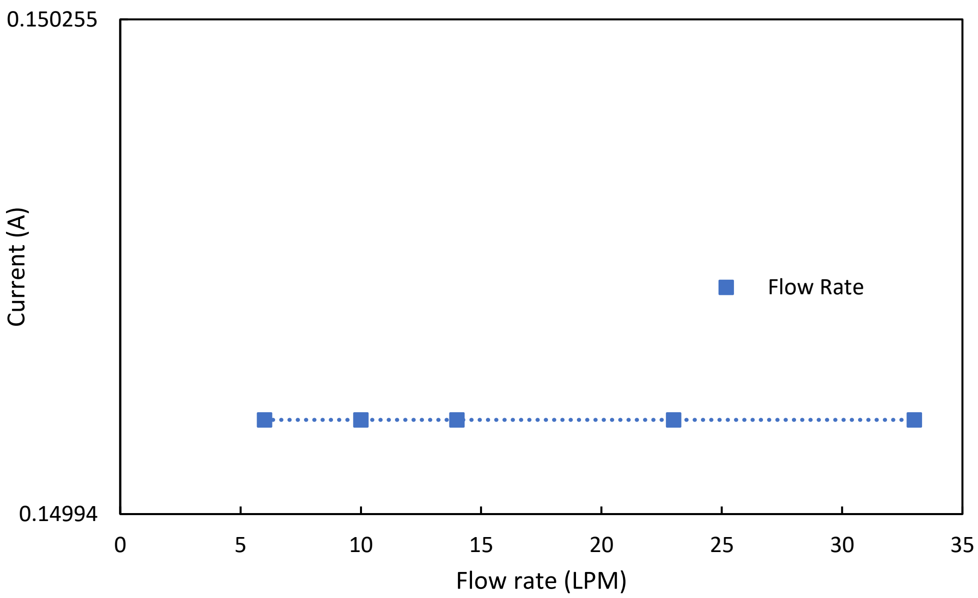


Fig. 4. Flow rate vs. Current for 5 bar working pressure

A proportional relationship between the water flow rate and the power generated through a working pressure of 5 bar was observed (See Figure 5). There is a gradual increase in the power generated as the water flow rate increased. For the 10 LPM of water flow rate, the power generated was 1.8 W. As the water flow rate increases to 33 LPM, the power generated rises to 6 Watt. The relationship of flow rate and power is affected by the voltage and current generated.

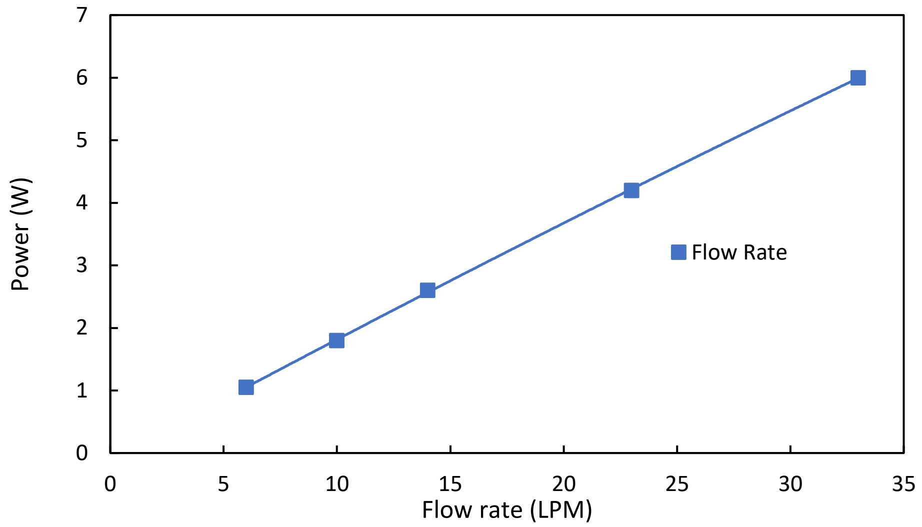


Fig. 5. Flow rate vs. Power for 5 bar working pressure

3.3 Power Generation for the Working Pressure of 3.2 Bar

Figure 6 represents the flow rate versus the angle of valve on a working pressure of 3.2 bar. There was a gradual increase in the flow rate of the water as the angle of valve in the pump increased. For the angle of 30° of the valves, the flow rate of the water was 8 LPM. For an angle of 90°, the water flow rate also increased to 27 LPM with a proportional relationship. For the working pressure of 3.2, the pressure reading after the turbine was 3.1, showing a minimal pressure drop.

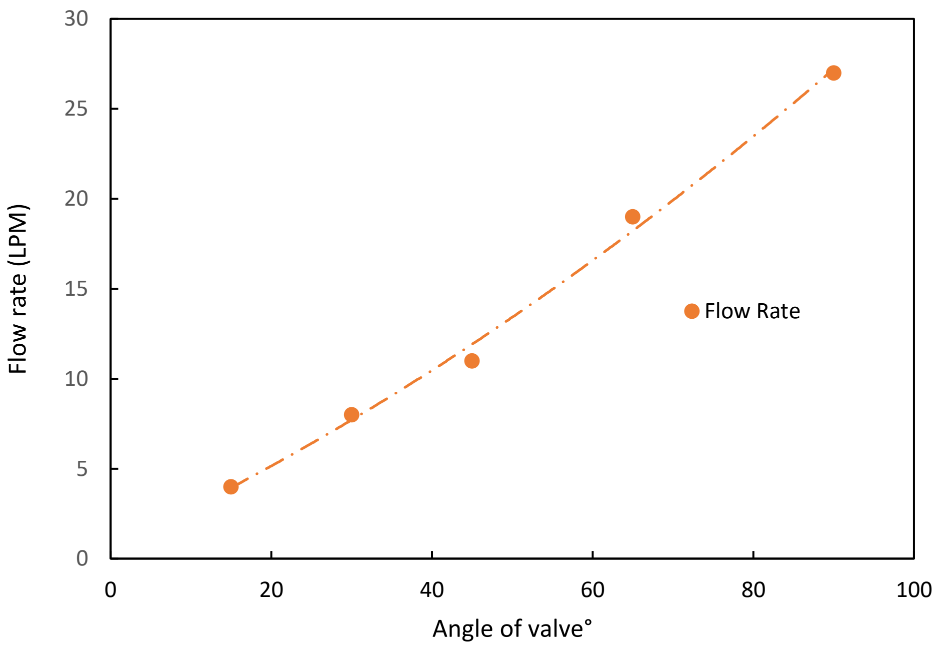


Fig. 6. Flow rate vs Angle of valve for 3.2 bar working pressure

Figure 7 shows a proportional relationship between flow rate and volt on a working pressure of 3.2 bar. As the water flow rate increases, the volt gained also rises. For a 4 LPM of water flow rate, the voltage gained was 5 V. For 19 LPM of flow rate, the voltage gained also rises, with a reading of 23 V.

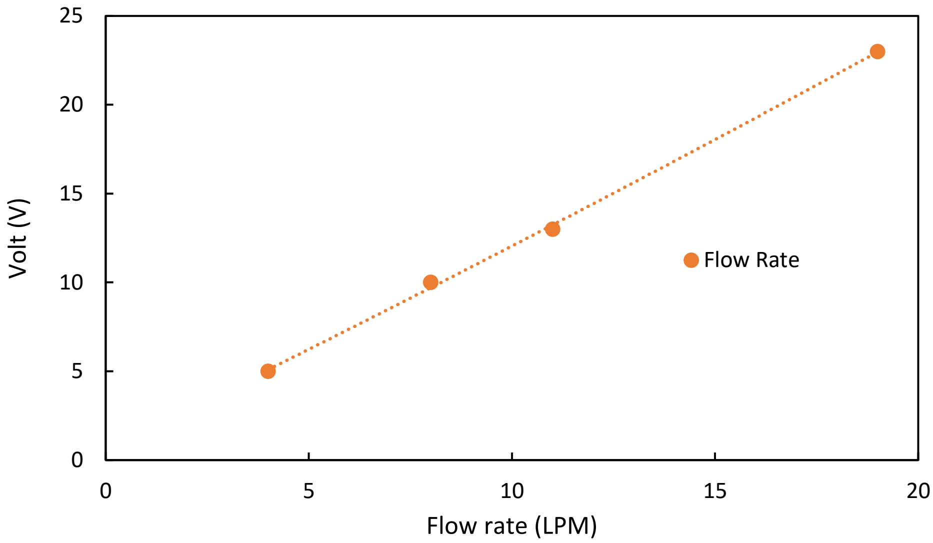


Fig. 7. Flow rate vs Volt for 3.2 bar working pressure

Figure 8 shows the relationship between flow rate and current on a working pressure of 3.2 bar. The constant current produced for the working pressure of 3.2 bar was 0.15 A.

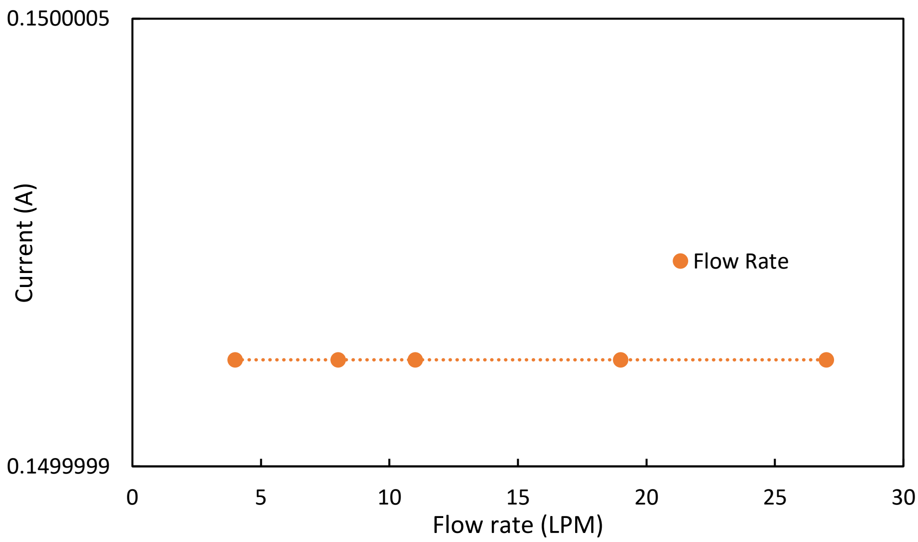


Fig. 8. Flow rate vs Current in 3.2 bar working pressure

Figure 9 shows power generated for different flowrates for a working pressure of 3.2 bar. A power of 1.5 W was generated for 8 LPM. When the water flow rate increased to 19 LPM, the power generated rises to 3.45 W. The relationship of flow rate and power is affected by the voltage and current generated. Moreover, the maximum power generated with the use of 3.2 bar working pressure through a half inch water pipe is 4.95 W by a flow rate of 27 LPM [20].

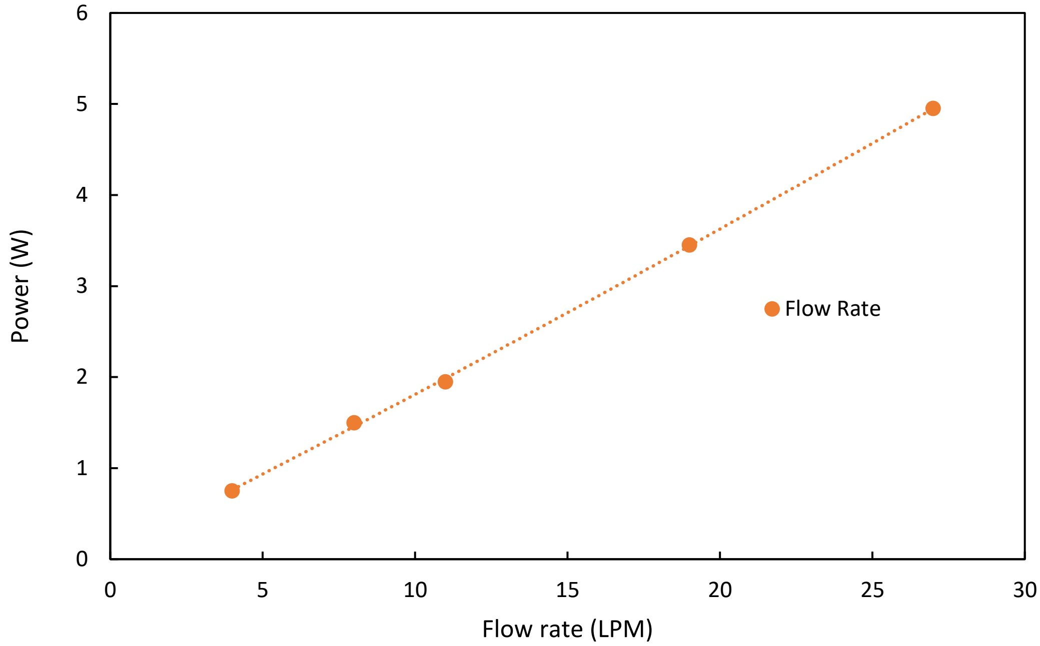


Fig. 9. Flow rate vs Power for 3.2 bar working pressure

3.4 The Influence of a Working Pressure of 1.5 Bar on Power Generation

Figure 10 depicts the flow rate vs the angle of valve on a working pressure of 1.5 bar. There was a gradual increase in the flow rate of the water as the angle of valve in the pump increased. When the angle of the valve was 45°, the flow rate was 7 LPM. For the 65°, the water flow rate also increased to 15 LPM. Moreover, it is found that in 1.5 bar pressure, the maximum flow rate can be obtained in a half inch water pipe is 22 LPM. For the case of 1.5 bar, the pressure reading after the turbine was 1.4 bar, with only a 0.1 bar drop in pressure. This means that the water which goes through the turbine can be transported safely to the water tank for the users and would not be affected by the losses that the turbine creates [27].

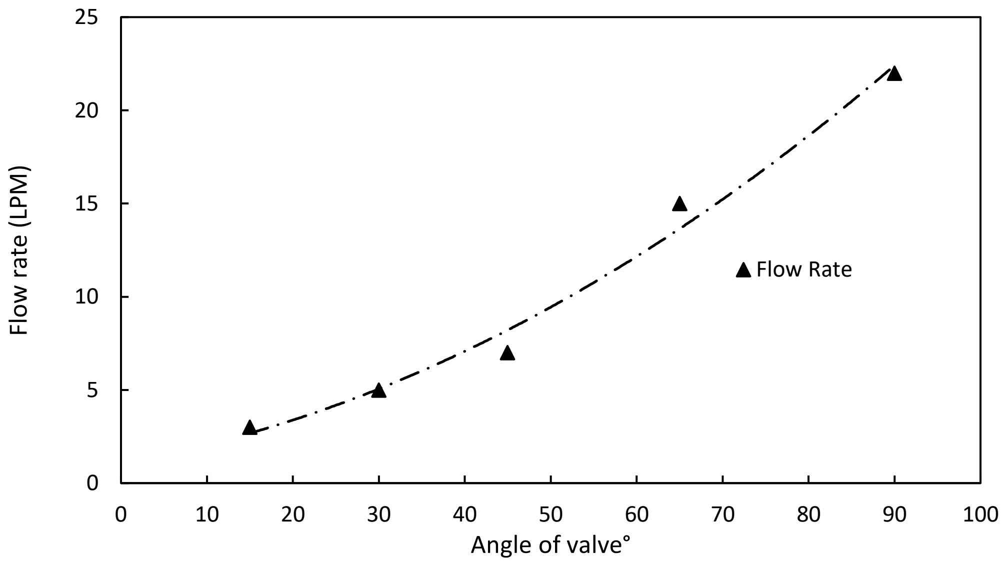


Fig. 10. Low-rate vs Angle of valve for 1.5 bar working pressure

Figure 11 shows a proportional relationship between flow rate and volt on a working pressure of 1.5 bar. The voltage gained at 3 LPM was 4 V. As the water flow rate increased to 15 LPM, the V gained also rises, with a reading of 18 V. It was also observed that with a working pressure of 1.5 bar and through a half inch water pipe, the maximum voltage that could be gained was 27 V via a water flow rate of 22 LPM.

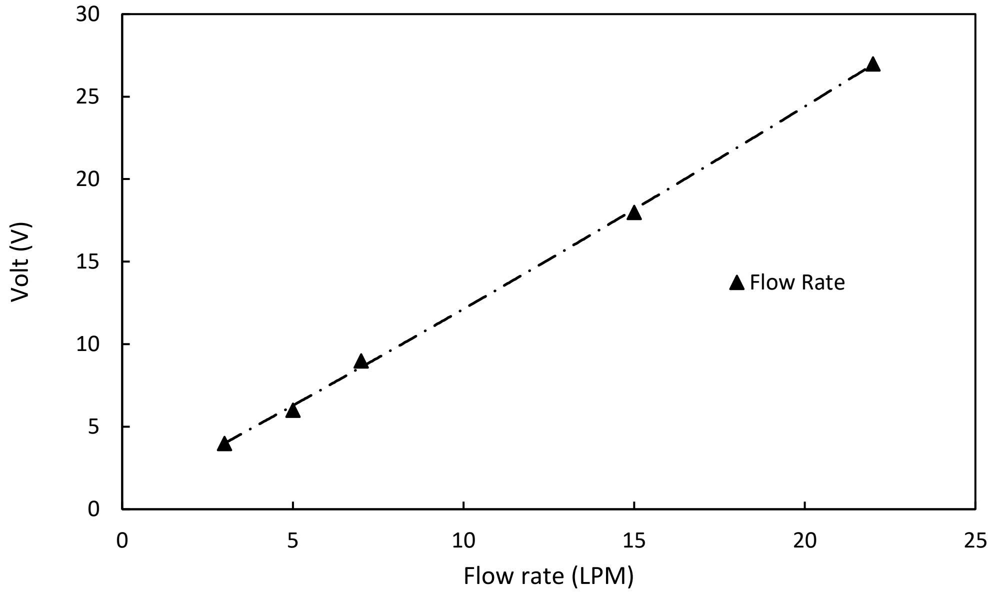


Fig. 2. Flow rate vs Volt for 1.5 bar working pressure

Figure 12 shows the relationship between flow rate and current on a working pressure of 1.5 bar. It can be seen that a 5 LPM has a current of 0.15 A. As the flow rate increased to 15 LPM, the current stayed constant with reading of 0.15 A.

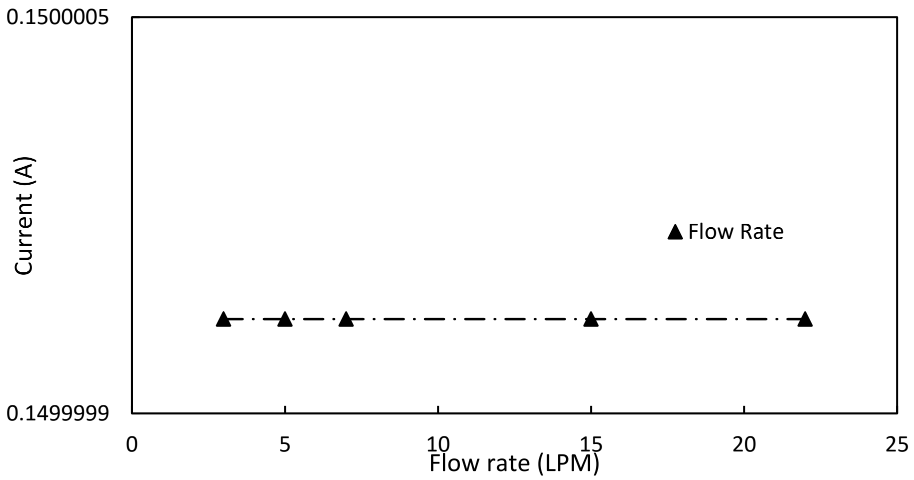


Fig. 12. Flow rate vs Current for 1.5 bar working pressure

It is observed in Figure 13 that a proportional relationship between the water flow rate and the power generated through a working pressure of 1.5 bar was observed. There is a gradual increase in the power generated as the water flow rate increased. For 5 LPM, the power produced was 0.9 W. And as the water flow rate increased, for instance 15 LPM, the power generated rises to 2.7 W.

Moreover, the maximum power generated with the use of 1.5 bar working pressure through a half inch water pipe is 4.05 watt by a flow rate of 22 LPM.

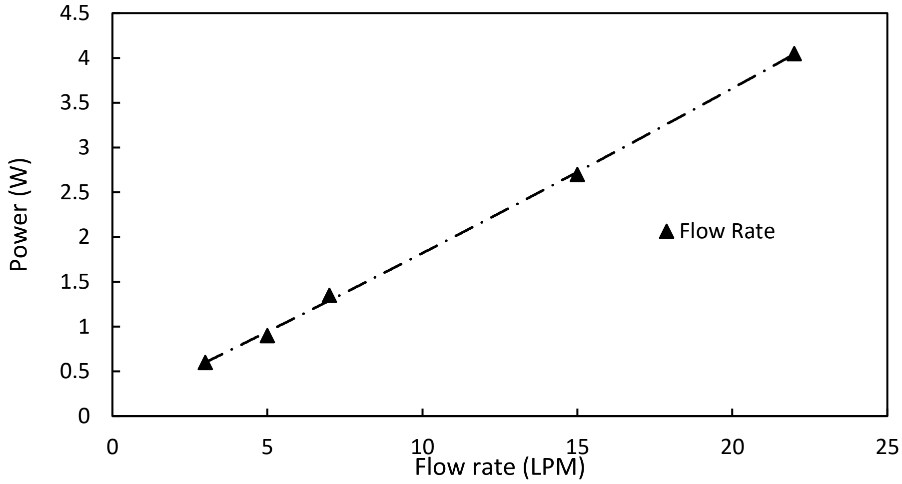


Fig. 13. Flow rate vs. Power for 1.5 bar working press

3.5 Comparison Between the Working Pressure

Figure 14 depicts the comparison among the three-working pressures. A higher working pressure gives us higher flow rate, which means a higher power that could be generated. For instance, when the flowrate was 33 LPM, the power generated was 6 W when using a working pressure of 5 bar. This means that the pressure 5 bar produces the maximum power and flow rate. On the other hand, a 3 LPM gave a power of 0.6 W when using of a working pressure of 1.5 bar. This means that the pressure 1.5 bar produces the minimum power and flow rate. Although, all points of the working pressure show a constant increase in generating power as the water flow rate increases, the power generated depends mostly on the flow rate, as the ability of the turbine to rotate increases (Suman *et al.,* [29]).

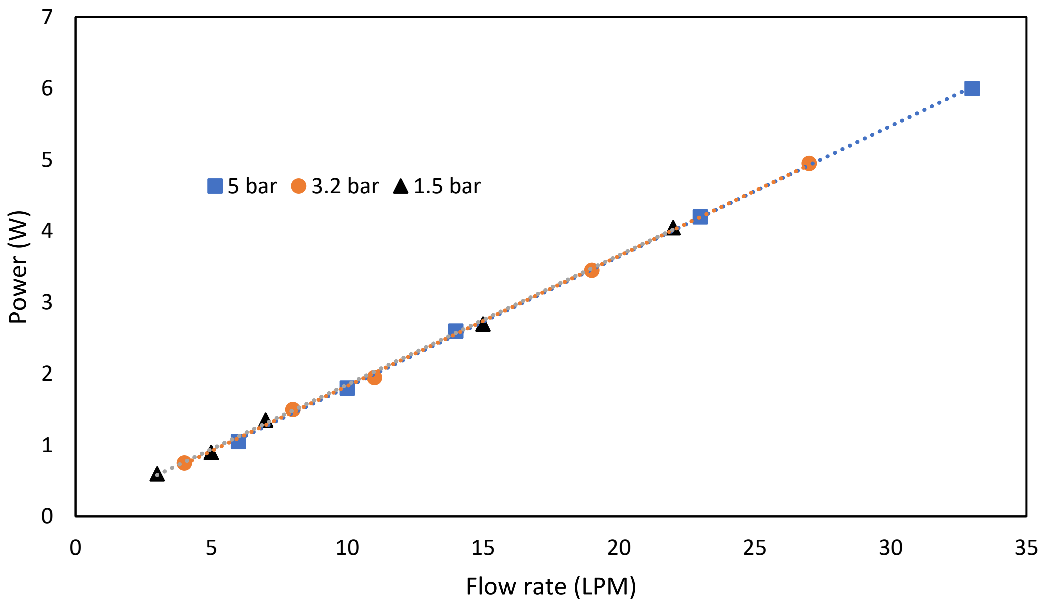


Fig. 14. Flow rate vs Power for a different working pressure

Figure 15 compares angle of values over flowrate for the three working pressures. As can be seen, the higher angle of valve in each working pressure, the more water flow rate produced. Like for the working pressure of 5 bar, as the angle of valve is placed to 90 °, the water flow rate produced is 33 LPM, which was the maximum. The 3.2 bar could produce a flow rate of 27 LPM, with a difference of 6 LPM between them.

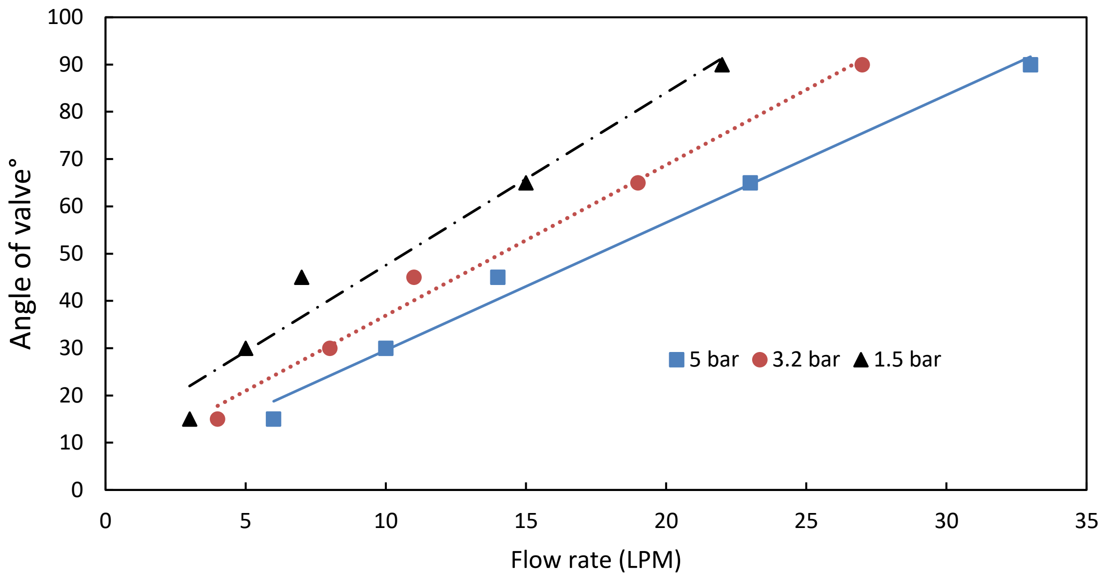


Fig. 153. Flow rate vs Angle of valve° for a different working pressure

Figure 16 shows a comparison between the water flow rate and volt gained for the three different working pressure. A higher working pressure gave higher volt generated. The maximum voltage was 40 V. When it is compared to working pressure of 3.2 bar in its maximum which is 27 litres per minute, then it could generate voltage of 33 V, with a difference of 7 V.

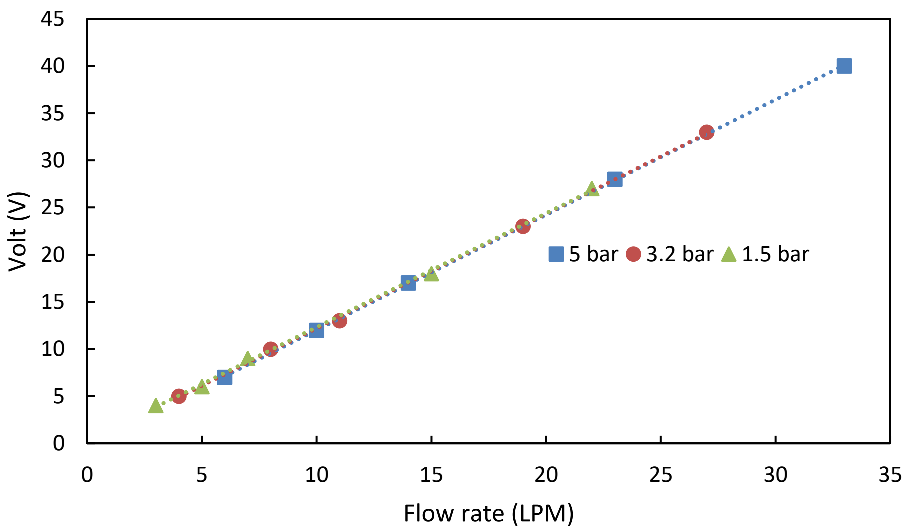


Fig. 16. Flow rate vs Volt for a different working pressure

Figure 17 shows the relationship between flow rate and current among the three-working pressure. Where there is a constant change in the current, as the flow rate rises. It can be seen that the current produced was 0.15 A for all working pressures.

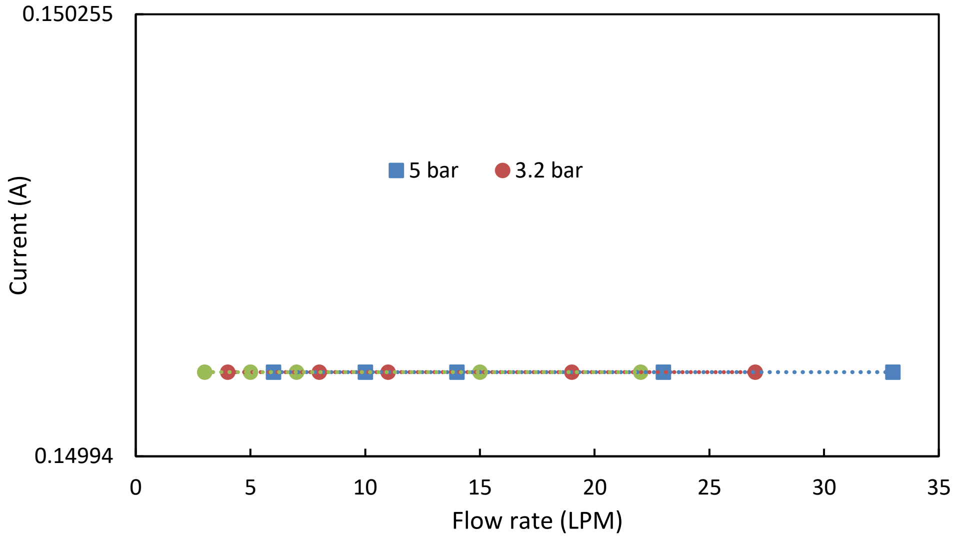


Fig. 17. Flow rate vs. Current for a different working pressure

Figure 18 shows the relationship between angle of valve and volt between the three working pressures. The higher working pressure, with the maximum angle of valve would generate, the higher voltage produced was. For a working pressure of 5 bar, with a 90° angle of valve, results to 40 V. However, with the same working pressure, and different angle of valve, results of voltage would differ. When the angle was 45°, 17 V was generated. Moreover, using working pressure 3.2 bar with maximum angle, 33 V was generated. When the angled reduced to 45°, the voltage was 13 volts, indicating a higher voltage produced for a higher angle of valve.

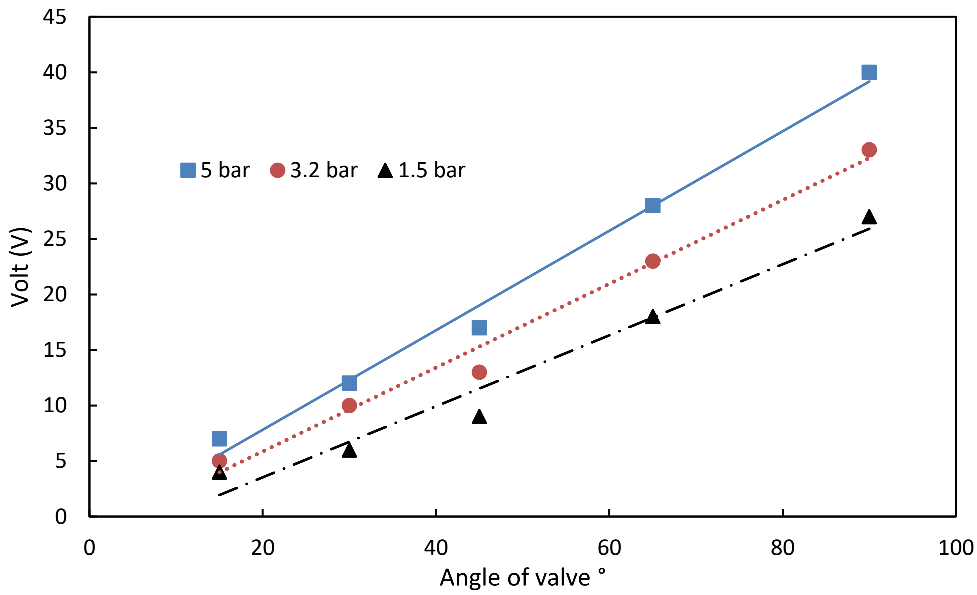


Fig. 18. Angle of valve vs Volt for a different working pressure

Figure 19 shows the relationship between angle of valve and power generated between the three working pressures. As in the working pressure of 5 bar, with a 90° angle of valve, the power produced was 6 W. However, with the same working pressure, and different angle of valve, the voltage produced were different. As in angle 45°, 2.6 W could be generated. Moreover, for a working pressure of 3.2 bar with maximum angle, 4.95 W could be generated. This was reduced to 1.95 wats when the angle was 45°.

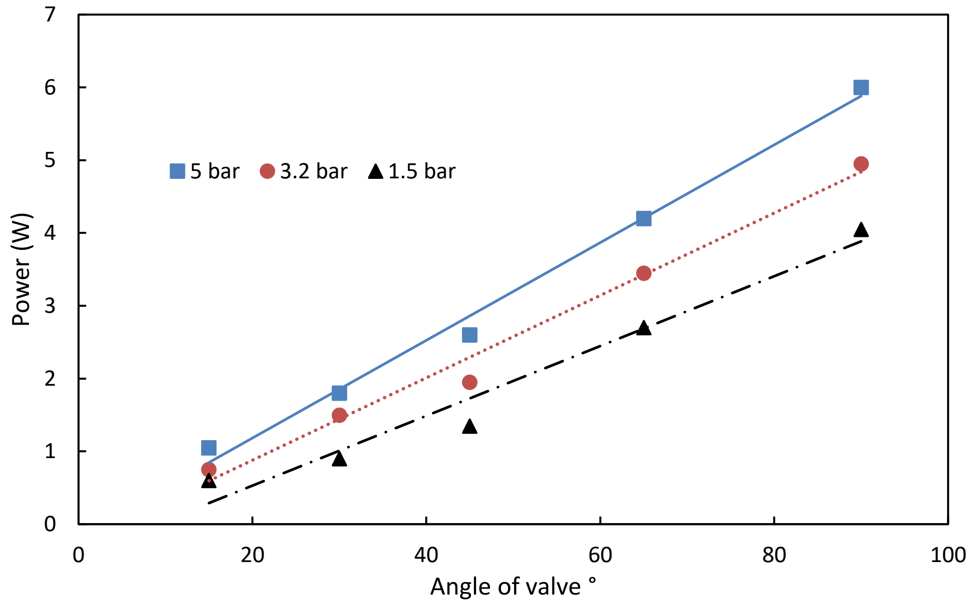


Fig. 19. Angle of valve vs Power for a different working pressure

3.6 Double Turbines in Series

It is observed in Table 1 that adding an extra turbine might affect the working pressure especially on a lower working pressure. This effect might interact the transportation of water to the water tank in the house. For a working pressure of 1.5 bar, the pressure after the turbine 2 decreased by 0.3 bar. Although, by adding another turbine, the energy generated could increase, as the current added the power generated would increase.

Table 1
Double turbine

No.	Working pressure *bar*	Pressure after turbine 1 *bar*	Pressure after turbine 2 *bar*	Total voltage *volt*	Total current *amperes*	Total power *Watt*
1	5	5	4.9	40	0.3	12
2	3.2	3.1	2.9	33	0.3	9.9
3	1.5	1.4	1.2	27	0.3	8.1

Figure 20 shows the relationship of the pressure after turbine 2 and total power generated. It is observed that the second turbine would affect the power generated positively. As it shows an increase in the power, like in point of pressure 4.9 bar, the power generated by the double turbine is 12 W. Moreover, the second turbine did not affect the working pressure just with a slight change that is not considered. Also, in point of pressure of 2.9 bar, a power of 9.9 W could be gained, but with a decrease of pressure with 0.3 bar. This did not affect the power generated negatively.

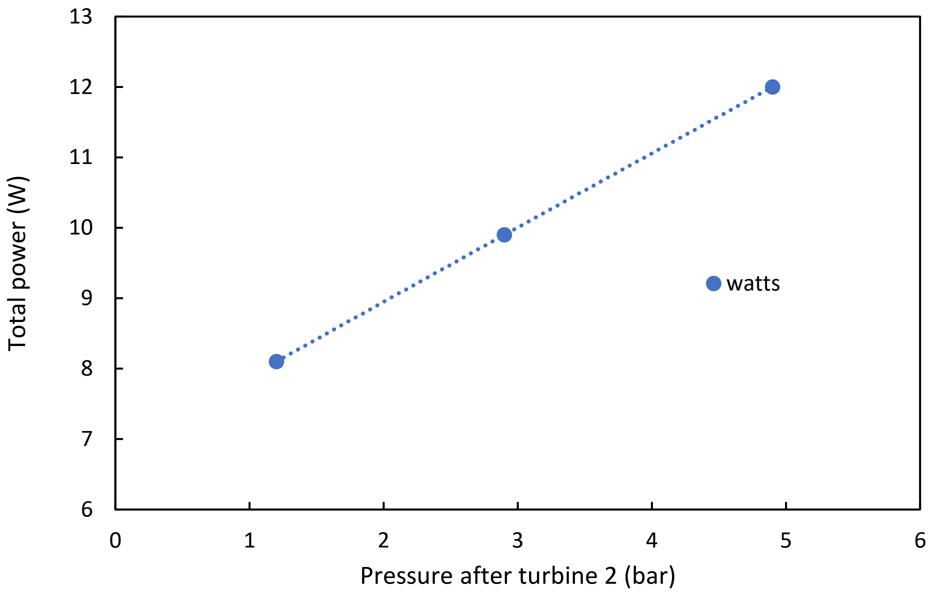


Fig. 20. Total power vs. pressure for a double turbine

3.7 Turbine Cut-Off Pressure

The hydropower turbine has been tested with lower working pressure, the result of the test shows that the ability of the turbine to work is after a working pressure of 0.4 bar.

3.8 Turbines Arranged in Parallel

Figure 21 shows voltage produced when the turbines were arranged in parallel. It was observed that the sum of voltage can be deduced by adding the voltages coming out of the three turbines, resulting in total voltage of 36.35 V. This shows the proportionality between the turbines number and the sum of voltage; therefore, the more the turbines the higher the sum of voltages would be.

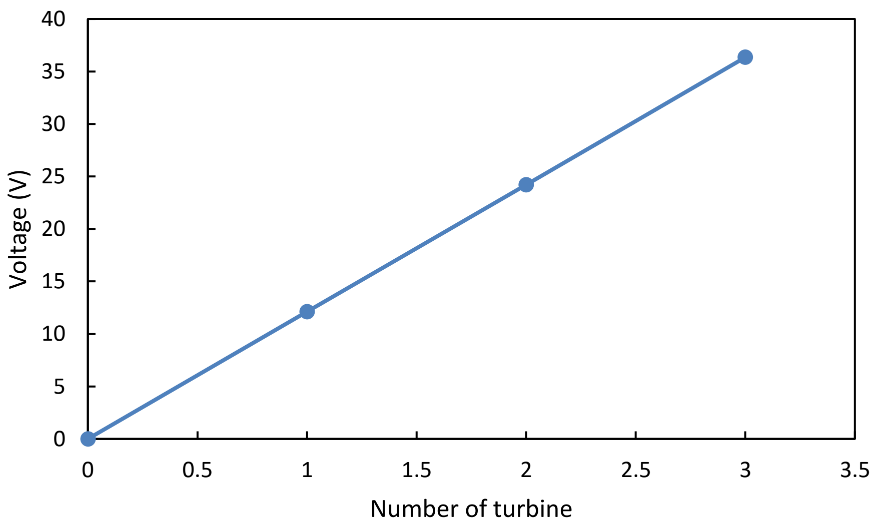


Fig. 21. Number of turbines vs voltage produced

4. Conclusion

This study investigates the hydropower energy generation by utilizing domestic water supplies as the header pressure between the maximum and minimum appears higher. Two sets of experimental setups were developed with turbine arranged both in series and parallel. The experiments were conducted using three working pressures, such as 1.5, 3.2 and 5 bar. The power generated depends mainly on the working pressure and the type of turbine. It was observed that the turbine mainly depends on the water flow rate, where the higher flow rate is achieved in working pressure of 5 bar which is 33 LPM and 6 W generated. Moreover, the turbine cut-off pressure was found to be 0.4 bar. For the two turbines arranged in series the power produced was increased to 12 W with a slight pressure drop of 0.1 bar after the second turbine, which is insignificant. However, the drop in pressure was observed to be slightly higher for the lower working pressure. It was also evidenced that arranging the turbines in parallel has also resulted in an enhanced power generation. Conclusively, as the drop in pressure was observed to be minimal, water transportation could be performed safely and would not be affected by the losses in the turbines. It is recommended to combine this renewable energy with other renewable energy for higher energy production.

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