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An Experimental Study on Effect of Disc Spacing and Disc Surface Roughness on The Performance of Tesla Turbine

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ABSTRACT

A breakthrough bladeless turbine, usually referred to as the "Tesla turbine," was one of Nikola Tesla's finest innovations but never saw commercial production. Tesla's original design was hampered by a dearth of technology and knowledge at the time of its creation. This turbine drives a set of stacked discs using frictional and viscous forces rather than blades. Losses in conventional turbines are caused by these factors. Researchers have attempted to create the turbine, but have never been able to match Nikola Tesla's expected efficiency. Tesla's original design was intended to replace inefficient full-scale turbines of the time. Parameters of the Tesla Turbine are the most crucial part of the turbine that influence its efficiency. This project aimed to investigate the effect of some parameters including the distance between the disc and the disc surface roughness towards the efficiency of the turbine. The study proved that reducing the gap between the discs helps to improve the performance of the turbine. This research also found out that surface roughness of the disc gives contribution towards the efficiency of the Tesla Turbine.

1. Introduction

The Tesla turbine which was invented by the famous scientist Nikola Tesla consists of a series of flat discs with nozzles applied to the side of the disc by a flowing fluid. By virtue of viscosity and the adhesion of the surface layer of the solvent, the fluid drags onto the discs. It spirals into the central exhaust as the fluid slows and contributes energy to the discs. The Tesla Turbine transfers momentum between the fluid and the discs using the boundary layer of the operating fluid. Thus, it depends on the frictional and viscous forces, which are the variables that cause conventional turbine losses. Tesla Turbine is also known as Prandtl or boundary layer turbine.

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In the years that followed, several experiments were conducted to assess the performance and efficiency of the Tesla-type micro turbine. There is theoretical as well as experimental research. There are certain parameters that affect the efficiency and performance of the turbine such as inlet nozzle angle, inlet pressure, disc thickness, number of disc and diameter of disc. There is a lack of research regarding the effect of disc surface roughness on the efficiency of the turbine. Apparently, there are some important engineering problems with the Tesla turbine design, despite its relative simplicity. The efficiencies are not better while it works, and in some instances, significantly worse than bladed designs. The rotor's efficiency is high, but the losses from the nozzles and diffusers required drops the efficiency significantly. Up until now, there is not much research that could achieve the best value of efficiency of the Tesla Turbine [1].

Several studies have been carried out on the studies of the disc spacing and surface finish of the Tesla Turbine. A total of 3 interdisc distance configurations were tested by Krishnan [2], in which 125 µm, 250 µm and 500 µm with a different number of discs and exit profiles for a total of 6 rotor stacks. The turbine size was kept unchanged overall. Increasing the distance resulted in greater generation of rotation per minute (rpm) due to the lower mass of the stacks of smaller discs. The effect of varying inter-disc spacing on turbine performance was also studied [3]. Air is used as the working medium and found that at a disc spacing of 0.6 mm, the setup achieved optimum efficiency. For spacing of discs smaller than 0,4 mm or wider than 1 mm, performance has rapidly declined. Several research also investigate in disc spacing parameter [4-7].

Tan [8] used statistical fluid mechanics to try to reduce the number of disks in previous works. Head loss was minimized by reducing the number of disks from 21 to 13. When the fluid exits the disk gap and turns 90 degrees to reach the outlet, it loses its head. The flow splits at the corners and is constrained to the vena contracta.

Romanin [9] put rotors with 8, 13 and 20 discs to the test. As the number of disks was increased from 8 to 12, the efficiency increased greatly. The efficiency obtained with 8 discs ranged from 0 to 10 %, while the efficiency obtained with 13 and 20 discs was roughly in the range of 10 to 20 %, with 13 discs providing the highest efficiency.

Meanwhile, Borate [10] investigated the effect of surface finish of the discs on the turbine. On three of the six sets of discs being tested, using a lathe, spiral grooves were engraved. 500 ra is the surface roughness. The grooves were machined along particular spiral paths to guide the incoming jet. This meant that long spiral paths were used to consume much of the jet flow's kinetic energy. The engraved discs showed an improvement in productivity by up to 6 %.

Several tests were performed in the years that followed to test the performance and efficiency of the Tesla-type microturbine [11-15]. Theoretical as well as scientific testing has been done by some researchers. There are some parameters that influence the turbine's efficiency and output, such as the angle of the inlet nozzle, the pressure of the inlet, the disc gap, the number of discs and the disc diameter. However, there is a lack of research which bring to the gap to study on the effect of the surface roughness on the efficiency of the turbine. Hence, this research focussed mainly on the effect of disc spacing and disc surface roughness on the efficiency of the turbine. For disc spacing, the measurement can be various and suitable depending on the size of the turbine. For disc surface finish, grooves were added onto the disc surface.

2. Methodology

The development phase concentrated on choosing the right microcontroller, relay and valve. To determine how well the control valve system manages turbine speed and voltage, it first be tested on a single turbine. If it doesn't work, the design will be redone; if it works, the system will be integrated into the quadcopter frame, which includes wiring, hose installation and valve placement. A leak test and component inspection was then followed. A tachometer was used to measure the turbine rpm in order to simulate propeller speed changes and assess speed variations. At this research conclusion, successful results were examined and discussed, while any problems were brought back to assembly checks.

2.1 Tesla Turbine Design

In this project, 5 discs were attached on the shaft. The design of the disc contains three holes on the surface of the discs. The function of the hole is to allow the water or any other mediums to flow through it. The placement of the nozzle is at the bottom of the chamber. The placement of the nozzle can be varied as long as the flow of the medium is directly in between the discs. In this experiment, the size of the nozzle used for inlet and outlet are the same.

After obtaining the required design criteria, the project was continued with a 3D drawing process (Table 1). The software used for 3D drawing was CATIA software. Note that, the designing process was divided into three different parts which were the chamber, the shaft and the discs. Figure 1 (a) represent the result of the assembled product. There were five total discs that were attached to the shaft. The hole on the surface of the disc must be aligned with each other. To make it easier for the rotor to rotate, there were a few distance gaps between the chamber and the rotor. On the other hand, Figure 1(b) 3.8 shows the complete part of the chamber.

Table 1
The constant parameters of the Tesla Turbine

Parameters	Measurement
Disc Thickness	0.25 cm
Disc Diameter	7 cm
Number of Disc	5
Length of Shaft	15 cm
Radius of Shaft	0.95 cm
Dimension of The Turbine Casing	11 cm x 11 cm x 9.5 cm
Size of Nozzle	1.5 cm
Clearance	1.0 cm

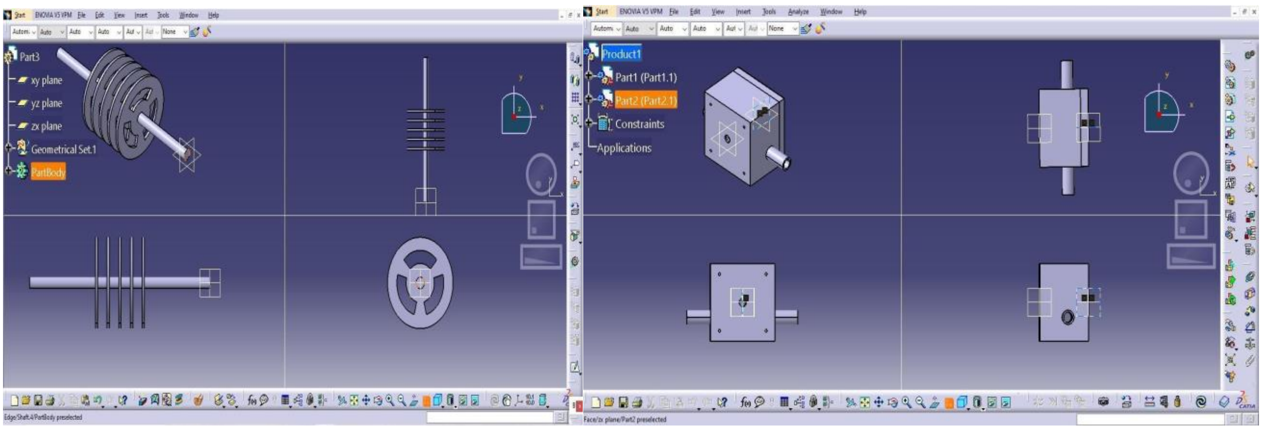
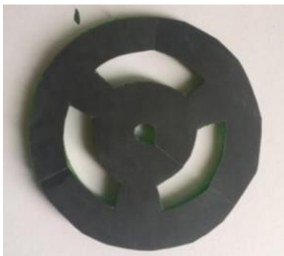


Fig. 1. The 3D drawing of the a) rotor (left) and b) Tesla turbine (right)

2.2 Fabrication of Tesla Turbine

The whole Tesla Turbine was 3D printed using two different 3D printer which were the Stereolithography (SLA) printer and Fused Deposition Modeling (FDM) printer (Table 2). SLA printer was used to fabricate the disc and also the shaft meanwhile FDM printer was used to fabricate the chamber. Next up is the changing the surface roughness of the surface of the discs. The second design and fabrication of this experimental process is changing the surface roughness. This fabrication was achieved by adhering sandpaper on the surface of the discs. There were three sandpapers used for this experiment with different grits which were 0, 1000 and 2000.

Table 2
The level of roughness of the disc surface

Grits	Level of roughness	Details
0	Roughest	
1000	Intermediate	
2000	Smoothest	

2.3 Experimental Setup

Figure 2 presents the schematic diagram of the experimental setup. A pressure gauge was utilised to obtain an accurate measurement of the water pressure. Water pressure can be regulated as a result of this. In alternative ways, the flow of water can be monitored instead of water pressure. The Tesla Turbine was connected to the water source and in between them, there was a pressure gauge in order to measure the inlet pressure. This experiment was quite easy to set up as long as there is a presence of water or air source or any medium that is required for the experiment.

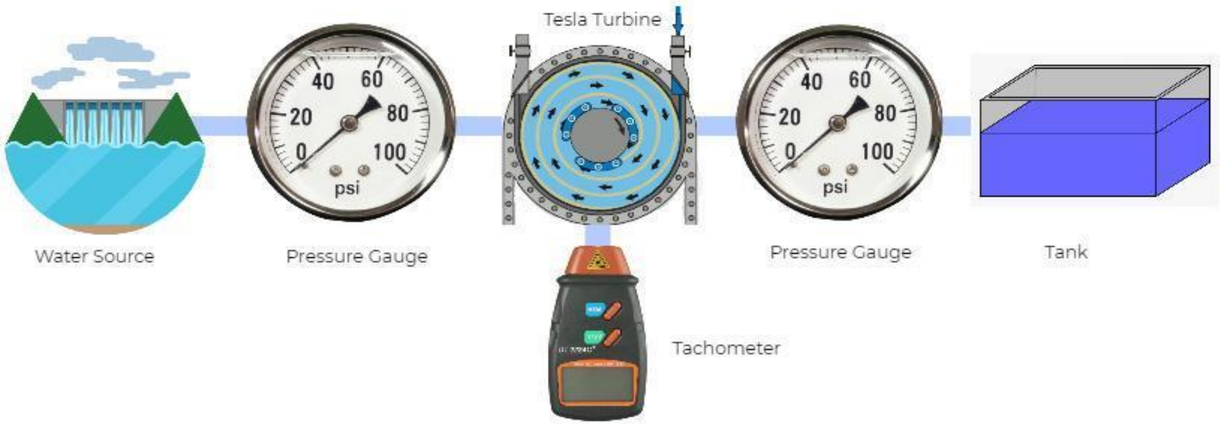


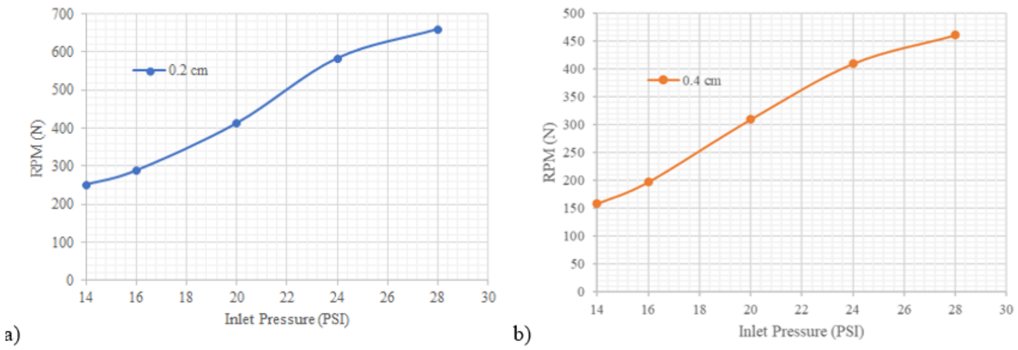
Fig. 2. Schematic diagram of the experimental setup

A tachometer can be used to precisely obtain the speed output (N). Thus, in this experiment, a DT2234C+ digital tachometer was used to measure the rpm of the turbine. DT-2234C+ digital tachometer is widely used and well-known for its convenience while using it and beginner friendly. The procedure for using this device was really uncomplicated. A reflective mark was applied on the disc then depressed the measure button and aligned the visible light beam with the applied target. Since the turbine is opaque, the measurement process was taken outside of the turbine. This approach was discovered to be both accurate and cost-effective.

3. Results

3.1 Microturbine Performance Without and With Propeller

Graph in Figure 3 shows the rpm value versus the Inlet Pressure. The inlet pressure was varied starting from 14 PSI until 28 PSI. The gap between the minimum pressure and the maximum pressure was not a constant gap because somehow some range of pressure reading produced the same amount of rpm value. This is because the turbine started to function well from the minimum pressure of 14 PSI. It is observed that only the turbine with the rotor of 0.2 cm and 0.4 cm could start to work with a pressure below 14 PSI. Thus, this experiment chose the minimum working pressure that worked for all models.



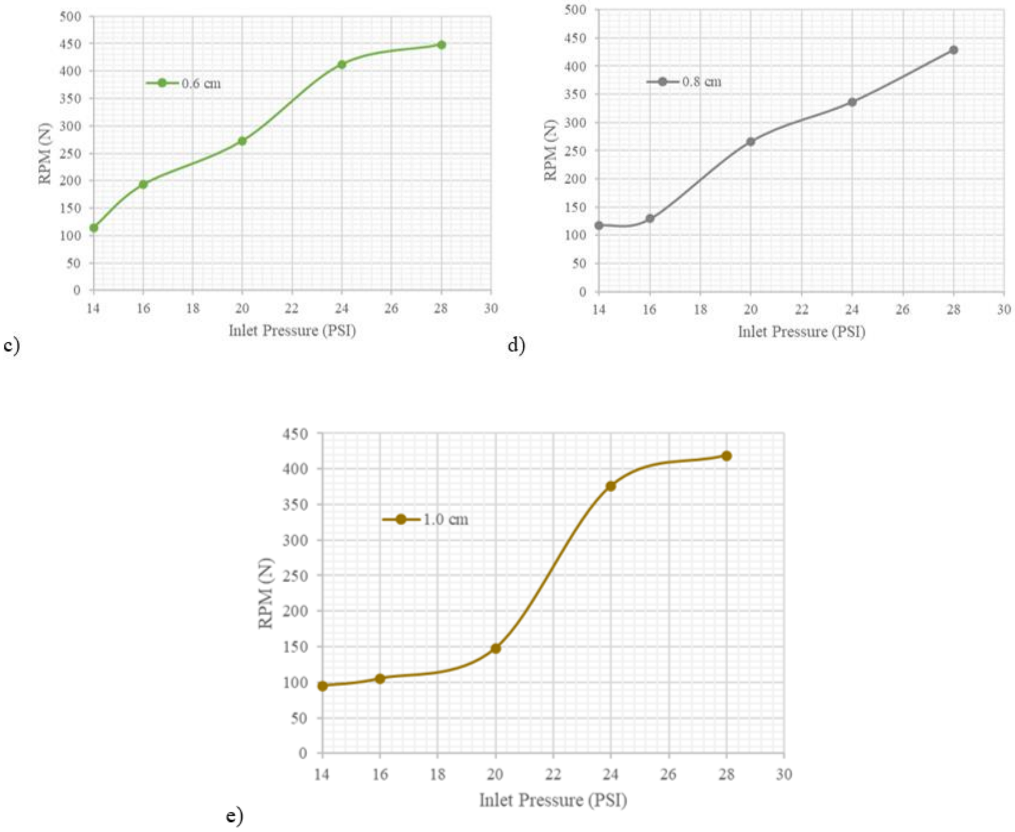


Fig. 3. Graph of rpm *vs* Inlet Pressure for different disc spacing. a) Disc spacing of 0.2 cm, b) Disc spacing of 0.4 cm, c) Disc spacing of 0.6 cm, d) Disc spacing of 0.8 cm and e) Disc spacing of 1.0 cm

The data was tabulated in the manner described above in order to provide a more accurate representation of the rpm value (Table 3). The model description has been described from the previous chapter. The greatest rpm value was 250.8 N at the lowest PSI, while the lowest value was 95.2 N. The greatest rpm value was 659.5 N at maximum PSI, while the lowest value was 418.8 N. The model that produced the highest rpm value at both PSI was the turbine with 0.2 cm disc spacing (Model 1), whereas the turbine with 1.0 cm disc spacing (Model 5) produced the lowest rpm value at both PSI. As the PSI increases, so does the speed. However, as spacing expands, the rate of change slows. This is because when the friction or shear force between the jet and the disc rises as the separation between them decreases, the revolving disc forms a boundary layer around the wall, and the jet does the same. The discs are dragged by a high-velocity jet boundary layer. Because the disc rotates at a modest speed, it tries to counteract the velocity of the jet.

Table 3
Tabulated result of the speed of the rotor

Pressure (psi)/rpm	14 PSI	16 PSI	20 PSI	24 PSI	28 PSI
Model 1	250.8	288.2	412.3	582.9	659.5
Model 2	158.6	197.6	309.7	409.6	460.8
Model 3	114.7	192.9	272.9	412.2	448.0
Model 4	117.6	129.2	266.6	336.7	428.9
Model 5	95.2	105.5	147.9	375.8	418.8

As illustrated in Figure 4, the combined graph of the rpm versus Inlet Pressure for all disc gaps. It can be obviously seen that Model 1 (disc gap: 0.2 cm) has shown a significant difference compared to the others. This indicates that the disc gap parameter gives a big contribution towards the performance of the turbine.

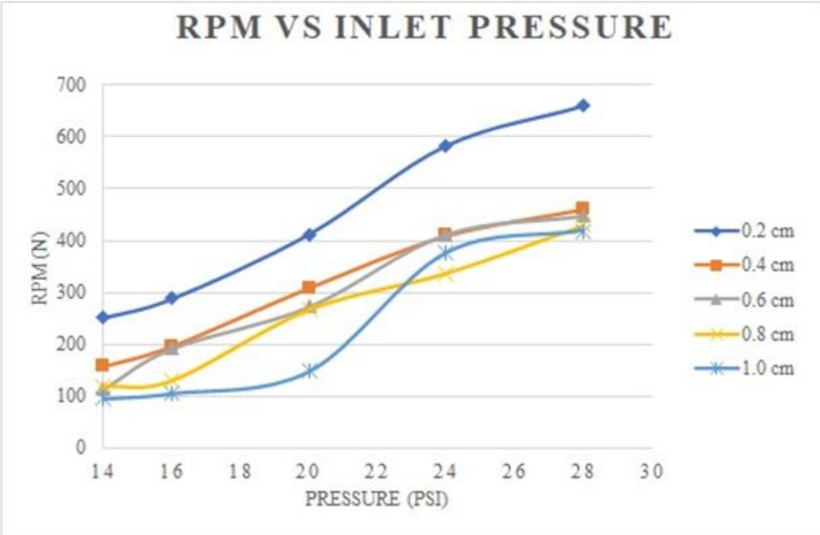


Fig. 4. The combination graph of rpm *vs* Inlet Pressure for all disc gap

To be precise, the fundamental concept of boundary layer thickness must be grasped. In the system, the fluid particles which are in close contact with the disc adhere to it and form a stationary layer. The next layer of molecules then tries to pull the stationary layer in the flow direction. However, in the process, they lose some energy to the stationary layer molecules and the same thing will happen with subsequent layers. This tendency of fluid particles to resist the flow of the other particles is known as viscosity. In this way, a velocity variety can be observed. The region up to which this velocity variation exists is known as the boundary layer region. Clearly inside the boundary layer, one fluid layer produces a drag force on the neighbours layer since a relative motion occurs between the layers [16]. However outside the boundary layer, no relative motion occurs between the layers or the force between layers is zero. It is called free flow. Thus, in this situation, lowering the disc spacing will eventually reduce the free flow that does not impart any energy and contributes a very little torque. The optimum disc spacing is when the boundary layer regions are touching each other. Then, the shear effect will be dominant between the discs spacing thus, will increase the quality of the performance of the turbine. Example given is as in Eq. (1):

$$\frac{RPM\ (1) - RPM\ (2)}{RPM\ (1)} x\ 100\% = \frac{659.5 - 460.8}{659.5} x\ 100\% = 30.13\ \% \tag{1}$$

The turbine with 0.2 cm could be the optimum disc distance that is suitable with the parameters of the turbine since according to Couto [13], for the best momentum transfer, the flow must be laminar and the disc gap must be twice the boundary layer. Calculating the boundary layer thickness for laminar and turbulent flows was part of the project. Also computed were the number of gaps between the discs for a particular mass flow, the moment coefficient, and the torque generated by n number of discs.

3.2 Disc Surface Finish Parameter

The graph in Figure 5 depicts the relationship between rpm and Inlet Pressure. Starting at 14 PSI and increasing to 28 PSI, the inlet pressure was adjusted when in fact a turbine with rotor of disc spacing of 0.2 cm could work less than minimum pressure of 14 PSI. This is to make the comparison analysis between the first and second phase of experimental testing easier.

Referring to Table 4, at the lowest PSI, the highest rpm value was 256.6 N, while the lowest was 159.4 N. At maximum PSI, the highest rpm value was 689.4 N, while the lowest was 542.0 N. The turbine with 0 grit disc surface roughness (Model 6) produced the maximum rpm value at both PSI, whereas the turbine with 1000 grit disc surface roughness (Model 8) produced the lowest rpm value at both PSI. Increasing the roughness of the surface finish of the disc contributed towards the increasing of the efficiency of the turbine. The frictional force between the jet and the disc increases as the surface roughness increases [17]. A small difference would still be counted even though the dissimilarities between one model to another was not too substantial.

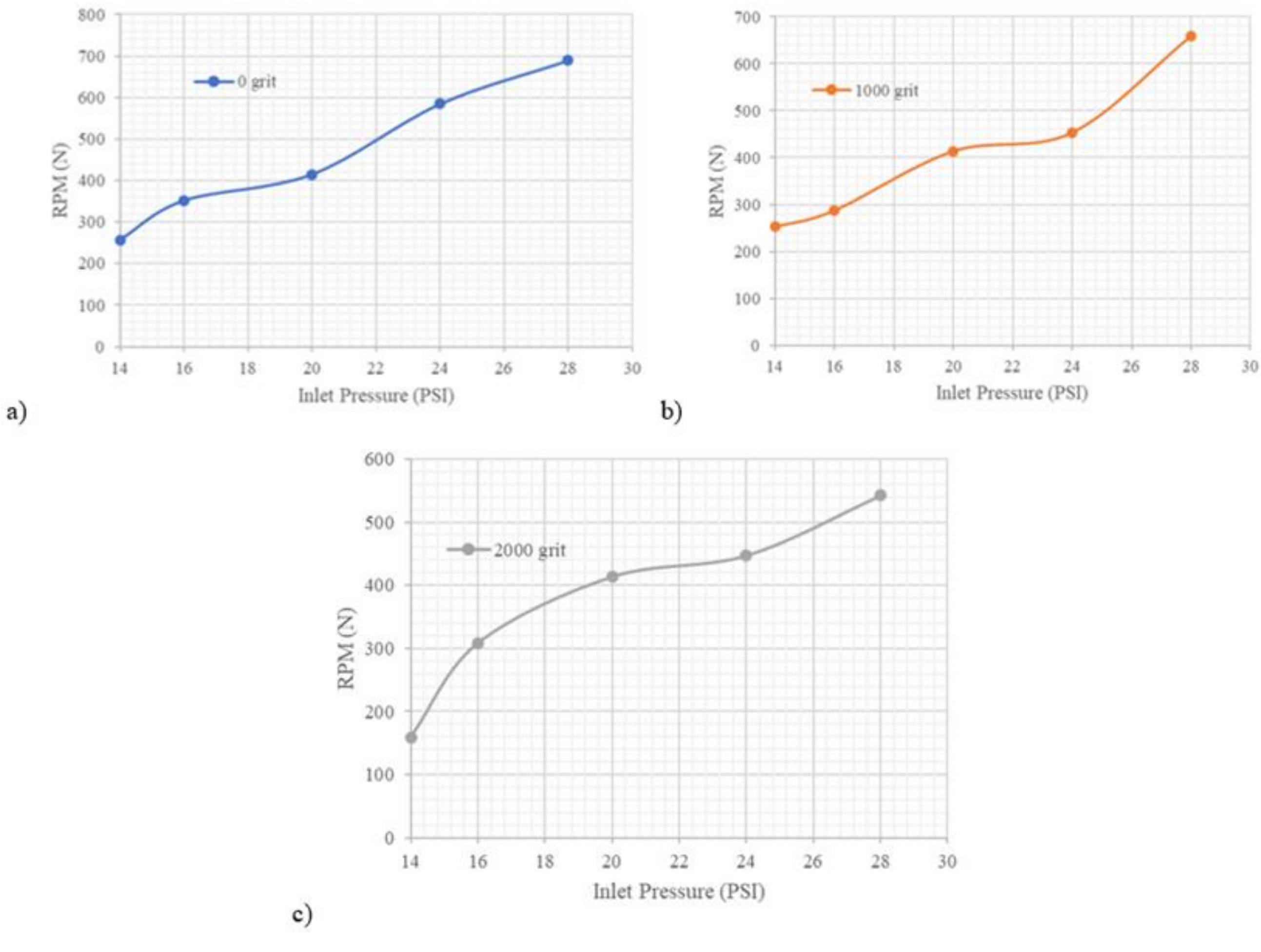


Fig. 5. Graph of rpm *vs* Inlet Pressure for different disc surface finish. a) Turbine with disc surface roughness of 0 grits, b) Turbine with disc surface roughness of 1000 grits and c) Turbine with disc surface roughness of 2000 grits

The combined graph of rpm against Inlet Pressure for all grits is shown in Figure 6. Noticed that the curve was closer to another curve when these measurements were plotted. This indicated that roughness of the surface could still be one of the parameters that contributes towards the efficiency of the turbine. Even if the differences between one model and another were not significant, a little difference would still be considered.

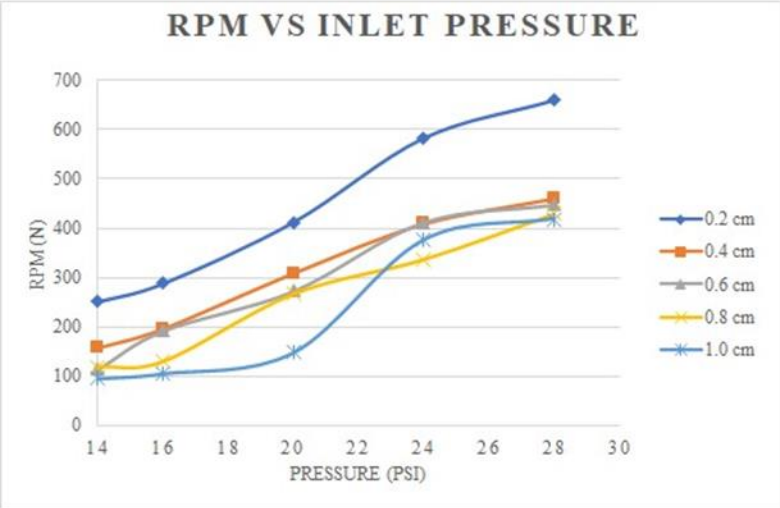


Fig. 6. The combination graph of rpm *vs* Inlet Pressure for all grits

There were several reasons on how the disc surface roughness affected the performance of the turbine. Increased disc surface roughness provides more surface area for the adhesive to make contact with while forming a bond [18]. Following that, the rough surface adds to the mechanical interlocking at the interface. In addition, surface irregularities may reduce crack propagation, resulting in stronger, more fatigue-resistant connections. Thus this helps to improve the performance of the turbine.

3.3 Percentage Difference

The rpm readings showed not much of a difference based on the Table 4 presented but it is important to take this parameter into account because small changes could make a big difference towards the performance of the turbine. As seen below is the percentage difference that this parameter made towards the value of the speed output. There was a few percent increase from the first model. Take example at the maximum pressure (28 PSI) as in Eq. (2):

Table 4
Tabulated result of the speed output for best model

Pressure/rpm	14 PSI	16 PSI	20 PSI	24 PSI	28 PSI
Model 1 (0.2 cm disc spacing, smooth disc surface roughness)	250.8	288.2	412.3	582.9	659.5
Model 6 (0.2 cm disc spacing, rough disc surface roughness)	256.6	351.3	414.6	584.5	689.4

$$\frac{RPM\ (6) - RPM(1)}{RPM\ (1)} x\ 100\% = \frac{689.4 - 659.5}{689.4} x\ 100\% = 4.5\ \% \qquad (2)$$

This percentage shown above indicates that changing the surface can make little contribution to turbine improvement. Borate [3] found out that increasing the surface roughness of the disc will help to increase the efficiency of the turbine by 5-6 %. In this experiment, it proves that the hypothesis is true.

4. Conclusions

A Tesla turbine is made up of a series of smooth discs with nozzles that apply a moving fluid to the disc's edge. The fluid drags on the disc due to its viscosity and the adhesion of the fluid's surface layer. The fluid spirals into the centre of the exhaust as it slows and contributes energy to the discs.

Several researches have demonstrated that Tesla Turbines have a bright future. Tesla turbines are the way ahead in the context of growing interest in renewable and clean energy resources. The efficiency of the turbine may undoubtedly be improved by putting more emphasis on the nozzle design, making it more viable. Because the parameters fluctuate depending on the fluid and turbine size, this will necessitate an application-specific strategy. Where conventional turbines are impractical, this Tesla Turbine offers a compelling alternative.

The Tesla turbine, despite its inefficiencies, has a number of advantages. Disks have cheaper production costs than blades, and their overall design is simpler and easier to construct [19,20]. In addition, the turbine can handle a wide range of fluids without causing significant harm to the discs. The results of this research show that the number of discs, disc spacing, and disc surface roughness all have a substantial impact on turbine performance. This research studied the performance of a disc turbine that operates on water as medium, while previous research and experiments had been done on air and steam.

For disc spacing, it is found that reducing the distance between the disc will help to increase the efficiency of the turbine. It utilizes impulse force as well as the boundary layer effect to achieve the proper spacing between discs. In comparison to the maximum gap, equipment vibration rises for minimum spacing at high speeds, so vibration analysis has become a significant element. For disc surface roughness, it is observed that increasing the surface could contribute towards performance of the turbine. The efficiency of a disc turbine can be boosted by a few percent which was 5 to 6% by selecting rougher discs, according to research [3]. One limitation of this research is the inability to directly observe the flow patterns within the turbine to assess the impact of surface roughness. Future research may employ CFD simulations to visualize the flow behaviour over the rough disc surfaces.

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