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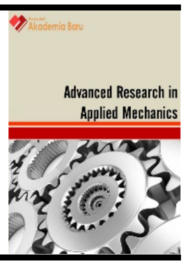

CFD Simulation of Tesla Turbines Performance Driven by Flue Gas of Internal Combustion Engine

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ABSTRACT

The reduced production of fossil energy, especially petroleum, has encouraged researchers to continuously increase the role of new and renewable energy as part of energy security and independence. A Tesla turbine is a device that can be used to recover wasted energy from exhaust gases, thereby increasing the overall energy use. The purpose of this study was to assess the performance of a Tesla turbine using various parameters such as engine speed, the gap between the disks, the diameter of the disks, and the number of disks. In this study, the performance of a Tesla turbine was simulated using computational fluid dynamics (CFD). The reference dimensions of this Tesla turbine are made with a slit diameter of 44 mm, a hole diameter of 10 mm, disc diameter of 140 mm, a disc width of 1.5 mm, a disc gap of 35 mm, a disc gap width of 4 mm, and a shaft length of 50 mm. The results of this study were in the form of torque and pressure drop values. In the variation of engine speed, the highest torque was at 1800 rpm with a torque value of 0.422 Nm, and the highest pressure drop was at 1800 rpm with a pressure drop value of 79161.5 Pa. In the disk gap variation, the highest torque is at a 7 mm disk gap with a torque value of 0.54 Nm and the highest pressure drop is at a 4 mm disk gap with a pressure drop value of 79161.5 Pa. In the variation of disk diameter, the highest torque was found on the disk with a diameter of 180 mm and a torque value of 0.831 Nm, and the highest pressure drop was on a disk with a diameter of 180 mm and a pressure drop value of 86753.5 Pa. In the variation of the number of disks, the highest torque was found at eight disks with a torque value of 0.765 Nm, and the highest pressure drop was found at eight disks with a pressure drop value of 82031.3 Pa. After performing this simulation, it can be concluded that at variations in engine speed, the higher the engine speed, the higher the value obtained and the variations in the disk gap, disk diameter, and number of disks. There are several values of torque that increase and decrease because the input value given cannot always increase the torque value in these variations.

Keywords:
Tesla Turbine, Combustion Engine, Flue Gas, Computational Fluid Dynamic

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1. Introduction

Reduced fossil energy production, especially petroleum, encourages researchers to increase the role of new energy and continuous renewables as part of maintaining resilience and independence. From the energy conditions required, it can be seen that the dependency energy that cannot be renewed is still very high. However, the availability of non-renewable energy continues to decrease. Efficient energy consumption is one way to achieve this goal. Saving energy, such as the recovery of waste energy, is not utilized.

A combustion motor is an engine that converts chemical fuels into heat energy, which is then converted into mechanical energy to the crankshaft round. Current conditions: Chemical energy of

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the fuel is not completely converted into energy. Even high-efficiency modern engines have only 25–50% thermal efficiency, and the remaining 50–85% of the low heating values of the fuel dissipate into the environment in the form of heat transfer and exhaust gas enthalpy. If the exhaust gas enters the surroundings directly, it not only wastes energy but also damages the environment [1].

A naturally aspirated (NA) internal combustion engine produces a large amount of waste heat. The combustion process of the fuel within the cylinder releases heat energy and is exhausted through the exhaust manifold and finally to the environment. The waste exhaust energy can be recovered using a turbocharger. The simplest definition of a turbocharger is a type of supercharger that is driven by exhaust energy. Another type of automotive supercharger is a belt-driven supercharger. However, the turbocharger is the focus of this subsection. A turbocharger is a type of gas turbine in which the heat and pressure in the expanding exhaust gas are used to increase engine power by compressing the air that enters the engine's combustion chambers. The turbine blades of the pump are spun by hot exhaust gases that leave the cylinders. A turbocharger component typically comprises (1) turbines, (2) shafts, (3) compressors, (4) waste gate valve (5), actuator (6) and center housing and rotating assembly (6) [2].

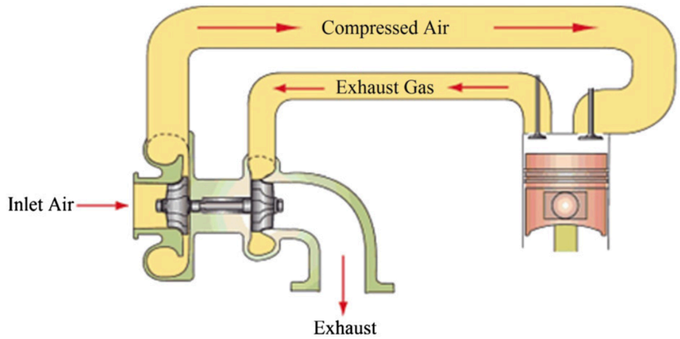

Fig. 1. Typical turbocharger with compressor wheel and turbine [2]

One of the most important parts of a turbocharger system is the turbine, which acts as the expander. Dumont dkk. [3] dan Zywica et al. [4] conducted a comparative analysis of turbines suitable for small- scale organic Rankine cycle systems. The results of the study indicate that the Tesla turbine is an attractive alternative to the expanders used so far.

The Tesla turbine is a bladeless radial turbine invented by Nicola Tesla in 1913 [5]. In contrast to conventional turbines, the principle of operation is based on the viscous effect of the fluid. Although the construction is unsophisticated, the phenomena in turbines are complex. The supply system was responsible for the increase in the kinetic energy of the working medium and its orientation relative to the disc. It may consist of a plenum chamber and set of nozzles or guide vanes [6].

The Tesla turbine rotor was the most distinctive component. It consisted of a set of thin discs mounted coaxially on the shaft. The liquid entering the rotor creates a pressure on the disc walls. The circumferential component of the stress can be considered the driving factor of the turbine, as opposed to a conventional turbine, where the wall stress contributes to a decrease in efficiency. This can be used to formulate alternative approaches for determining efficiency.

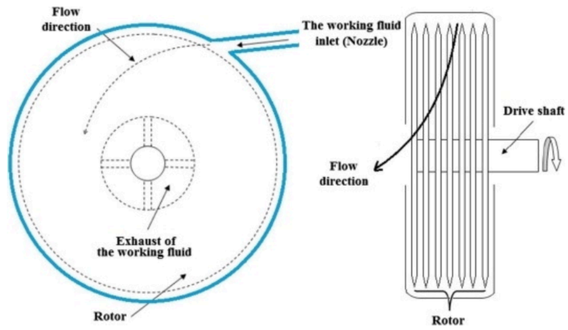

Fig. 2. Flow Direction of fluid in Tesla Turbine

Many researchers have conducted numerical and analytical investigations of the flow in the rotor. Boyd and Rice [7] derived a two-dimensional (2D) analytical model for an incompressible flow. Carey [8] developed a one-dimensional model of a rotor, in which viscous shear forces are replaced by body forces. Research has shown that Tesla turbines applied to small-scale Rankine systems can achieve isentropic efficiencies greater than 75%. The model is confirmed to give results in agreement with numerical simulations of real turbines [9], and further improvements of this model are presented in [10-11], where the flow is treated as turbulent and compressible considering the radial pressure gradient. The model agrees well with the experimental data in the low and medium ranges of rotational speed but differs at high speeds. Sengupta [12] developed a three-dimensional model of flow in a rotor, in which the impact of inertial, viscous, Coriolis, and centrifugal forces on fluid dynamics and the resulting power is described. Talluri [13] presented a two-dimensional analytical model that considered real fluid properties depending on local variables.

One of the most important parameters is the quality and shape of the surface of the disc. For microchannels where the relative roughness is higher than 0.05, flow constriction becomes an important factor [14]. Rusin *et al*. [15] proved by numerical simulation that a suitable roughness value can lead to a 35% increase in output power. Another important factor affecting the turbine efficiency is the disc spacing. Qi dkk. [16] investigated the optimal distances for two sets of inlet system configurations: one-to-one, where one nozzle supplies exactly one slit, and one-to-many, where one nozzle supplies all slits.

Another important area of research regarding the Tesla turbine is its dynamic behavior. Owing to the extremely high rotational speed, which often exceeds 20,000 rpm, the resulting vibration can be a serious problem.

The results of a comprehensive numerical and experimental analysis of the Tesla turbine were provided by Rusin *et al*. [18]. The turbine rotor had five discs with a diameter of 160 mm and a gap between discs of 0.75 mm. The nozzle kit consisted of four divergent nozzles with a minimum cross-sectional height of 2.85 mm. The probe was carried out in air in a subsonic flow regime at three pressure ratios:1.4, 1.6 and 1.88. The maximum output power was 126 W, and all power characteristics were in accordance with the numerical calculations. The efficiency of the turbine can exceed 20%, assuming elimination of the impact of the lateral gap between the disc and casing. The data presented can be used as a benchmark for validating analytical and numerical models.

The purpose of this study is to review the effect of engine rotation, gaps between disks, disk diameter, and the number of disks on torque, and to examine the pressure drop of Tesla turbines.

2. Methodology

According to Brieter and Pohlhausen, the ideal disk gap size for maintaining a boundary layer is [19].

$d = \pi(\mathrm{n}/w)^{1/2}$ (1)

Where d is the gap size, n is the fluid kinematic viscosity and w is the angular velocity of the rotor. Pohlhausen's parameter, often known as π was measured in the range of $\pi \leq 2.5 - 3.5$. The relationship between the inertia and viscous forces is given by the Reynolds number

$Re = (4/3)cVd/\mu$ (2)

where Re is the Reynolds number, c is the flow density, V is the relative flow velocity, d is the disk gap, and μ is the dynamic viscosity flow coefficient. Newton's second law of rotation states that the angular acceleration is caused by a force operating in the tangential direction. As a result, the torque, which is a measure of the spinning force, can be written as

$T = r \times F$ (3)

where T is the torque, r is the distance between the axis of rotation and the site where the force is applied, and F is the force exerted on the item.

According to Bernoulli's theorem, the sum of all sources of mechanical energy in a fluid along a streamline is the same at all places on that streamline. As a result, a popular method in terms of the total head H is written as

$H = p/\rho g + V2/2g + z = Constant$ (4)

where H is the head, P is the selected point pressure, V is the airflow velocity, z is the elevation height, ρ is the air density, and g is gravitational acceleration. The horsepower of a Tesla turbine can be converted into a turbine head using the energy grade line, and is represented as

$H_T = \omega T_{shaft}/\rho g Q$ (5)

where T_{shaft} is the shaft torque, ω is the rotational speed, and Q is the volumetric flow rate through the turbine.

The efficiency of a turbine is determined by the net head H rather than the gross head H_{gross}. Specifically, $\eta_{turbine}$ is the ratio of the work done by the shaft to the work done by the working fluid, which in this case is the flue gas. it is provided by

$\eta_{turbine} = \omega\ T_{shaft}/(gHQ)$ (6)

Tesla turbine geometry using Autodesk Inventor 2021 software, with the design shown in Figure 3 as follows

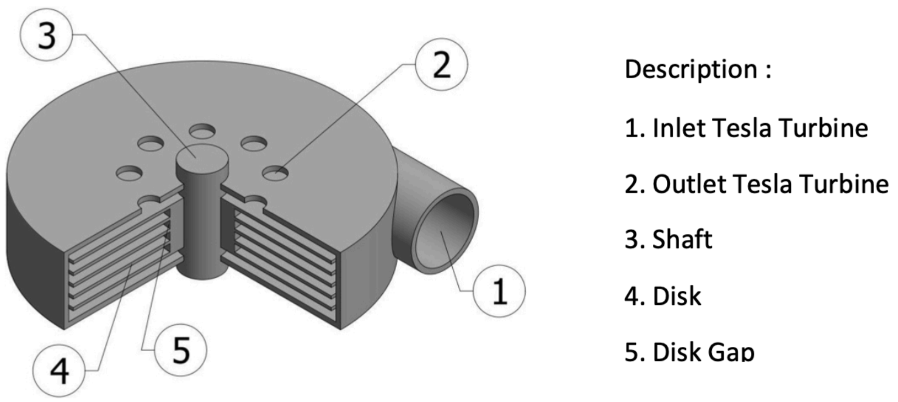

Fig. 3. Tesla Turbine Design

The dimensions of the Tesla turbine design in this study are as follows :

- Diameter Inlet: 44 mm
- Diameter Disk: 140 mm
- Diameter Disk Gap :35mm
- Shaft length : 50 mm
- Diameter Outlet : 10 mm
- Disk Thickness : 1,5 mm
- Disk Gap :4mm

4. Data and Result

4.1 Engine Rotation Relationship to Torque and Pressure Drop

Engine rotation affects the mass flow rate of the exhaust gases. The higher the engine rotation, the higher is the rate of gas mass flow. The input values based on the variation in engine rpm are listed in Table 1.

Table 1
Data input

Engine Rotation (rpm)	Mass Flow Inlet (kg/s)
1400	0.020
1500	0.022
1600	0.023
1700	0.024
1800	0.026

The results of the pressure distribution in the fluid domain of engine rotation are shown in Figure 4. The result of the pressure distribution in the fluid domain shows how the pressure difference obtained in the fluid domain is based on the gradation colors found in Figure 2 with variations of 1400, 1500, 1600, 1700, and 1800 rpm. The inlet of the Tesla turbines was red. This shows that the greatest pressure exists there. The inlet was the first part of the flow. The fluid produces an initial moment to drive the disc of the Tesla turbine.

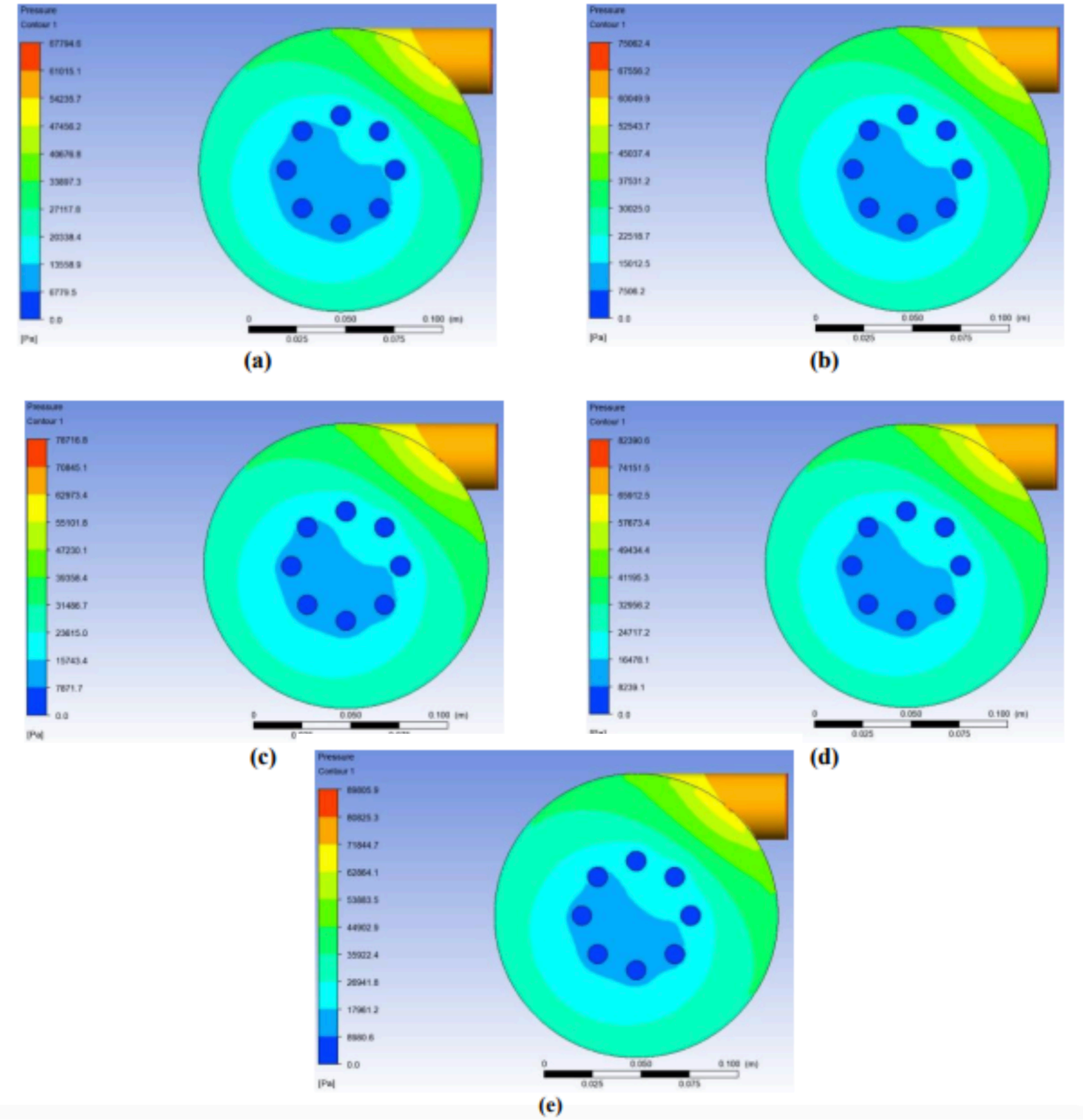

Fig. 4. Contour distribution pressure on the domain fluid with engine rotation (a) 1400 rpm, (b) 1500 rpm, (c) 1600 rpm, (d) 1700 rpm, (e) 1800 rpm

The relationship between variations in engine rotation, torque, and pressure drop is shown in Figure 5. When every engine rotation increased, the torque and pressure drop values increased. This was due to the mass flow inlet. The obtained from each engine rotation increased with increasing rpm. On that graph, It is seen that the highest increase in torque is located between 1700 rpm and 1800 rpm, where the torque value at 1700 rpm is 0.392 Nm and increased to 0.422 Nm at 1800 rpm, the increase in torque value reaches 0.030 Nm and the lowest increase in torque is in between 1500 rpm and 1600 rpm, where the torque value at 1500 rpm is 0.362 Nm and the torque value at 1600 rpm is 0.377 Nm, the increase in torque value only reached 0.015 Nm and also at between 1600 rpm and 1700 rpm, where the torque value at 1600 rpm is 0.377 Nm and torque value at 1700 rpm is 0.392, an increase the torque value also only reaches 0.015 Nm.

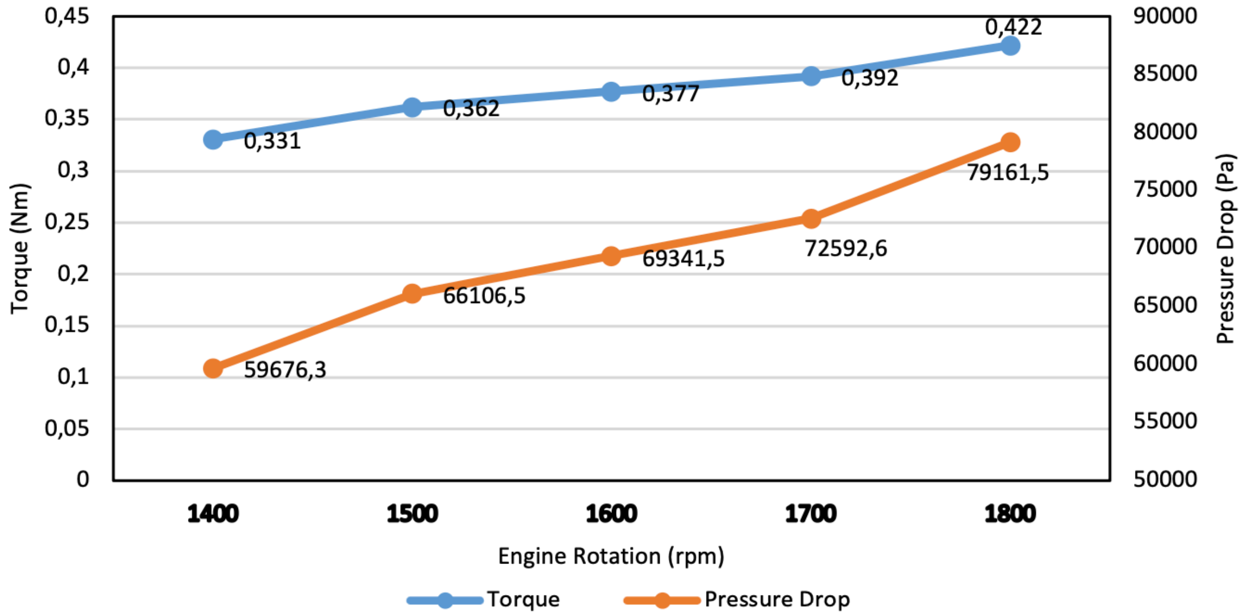

Fig. 5. The relationship between engine speed and torque and pressure drop

The pressure drop value on the engine rotation variation can also be seen in Figure 5, wherein the 1400 rpm variation, the value obtained is 59676.3 Pa and in later variations of 1500 rpm, 1600 rpm, 1700 rpm, and 1800 rpm continues to increase the pressure drop value. Based on the results of the calculation, the pressure drop value of this variation continues to increase along with the increased value of the mass flow inlet obtained from the engine rotation of the engine itself.

4.2 Disk Gap Relationship to Torque and Pressure Drop

The input parameter used in the variation of the disk gap relationship to this torque is the mass flow rate of the combustion motor exhaust gas. Mass flow rate of exhaust gases used in maximum engine rotation (1800 rpm).

The relationship between the disk gap variation and torque and pressure drop is shown in Figure 6. Where each increased size of the disk gap, this makes the torque increase, but it does not in a disk gap that measures 8 mm. Precisely on disk gaps measuring 8 mm experienced the decreased value of torque obtained. This is because the disk gap measuring 4 mm, 5 mm, 6 mm, and 7 mm can still provide higher pressure against disk gaps, while a disk gap of 8 mm is already classified as a gap that is too large with the input provided, resulting in a decrease in torque value obtained in the disk gap size of 8 mm.

As for the pressure drop value on gap variations, the disk can also be seen in Figure 6, wherein the variation in the pressure drop value on the disk gap size of 4 mm is 79161.5, and the pressure drop value on the next variation is a variation of 5 mm, 6 mm, 7 mm, and 8 mm disk gap continues to decrease. This is due to the increasing size of the disk gaps, and each variation creates a large amount of pressure. The obtained is decreasing and turbines tesla apply the centrifugal force that occurs in the part of the disk that is affected by one of them with the size of the disk gap, so that the larger the size of the disk gap, the lower the pressure drop value.

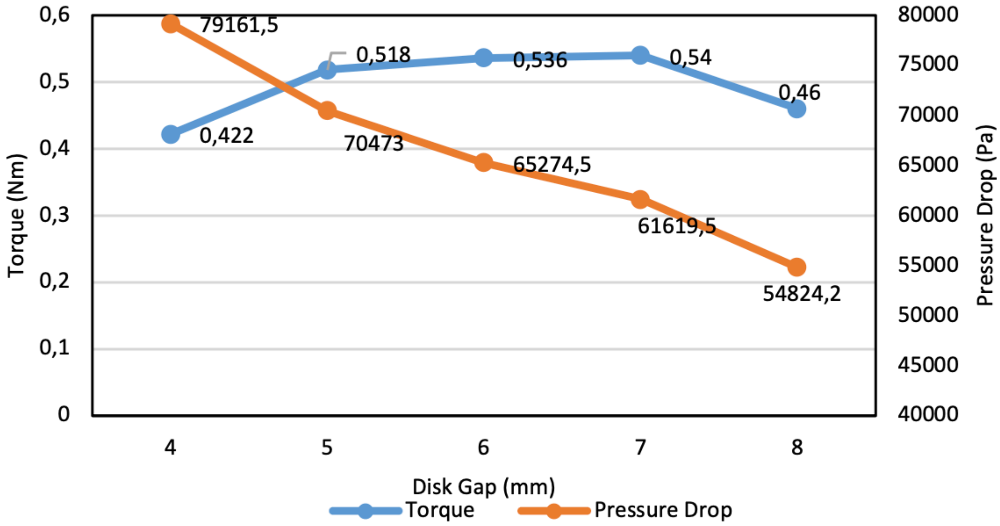

Fig. 6. Relationship of disk gap to torque and pressure drop

4.3 Disk Diameter Relationship to Torque and Pressure Drop

The input parameter used in the variations in the relationship of the disk diameter to this torque is the mass flow rate of the combustion motor exhaust gas. The exhaust gas mass flow rate was measured using maximum engine rotation (1800 rpm).

The relationship between the variations in disk diameter, torque, and pressure drop is shown in Figure 7. When each increased the diameter of the disk, the value of torque was increased, but not when the diameter of the disk was 180 mm; precisely, when the diameter of the disk was 180 mm, the torque value decreased significantly. This is because the disk diameters of 140 mm, 150 mm, 160 mm, and 170 mm can still receive the pressure given from the location of the inlet, so that the occurrence of centrifugal force can provide a torque value that is greater than the diameter of the disk size of 180 mm, while the diameter of the disk size of 180 mm is already classified as a size. A disk diameter that is too large with input is given, so that there is a decrease in the value of torque obtained at a disk diameter of 180 mm.

The pressure drop value on the diameter variation The disk can also be seen in Figure 7, where each at the level of disk diameter then the pressure drop value that is earned will increase. This is because the Tesla turbine applies centrifugal force so that the increasing diameter of the disk causes the fluid to put more pressure on this part of the disk. This is also affected by the surface area of the disk, in which the higher the diameter of the disk, the higher the pressure drop obtained from variations in the diameter of the disk.

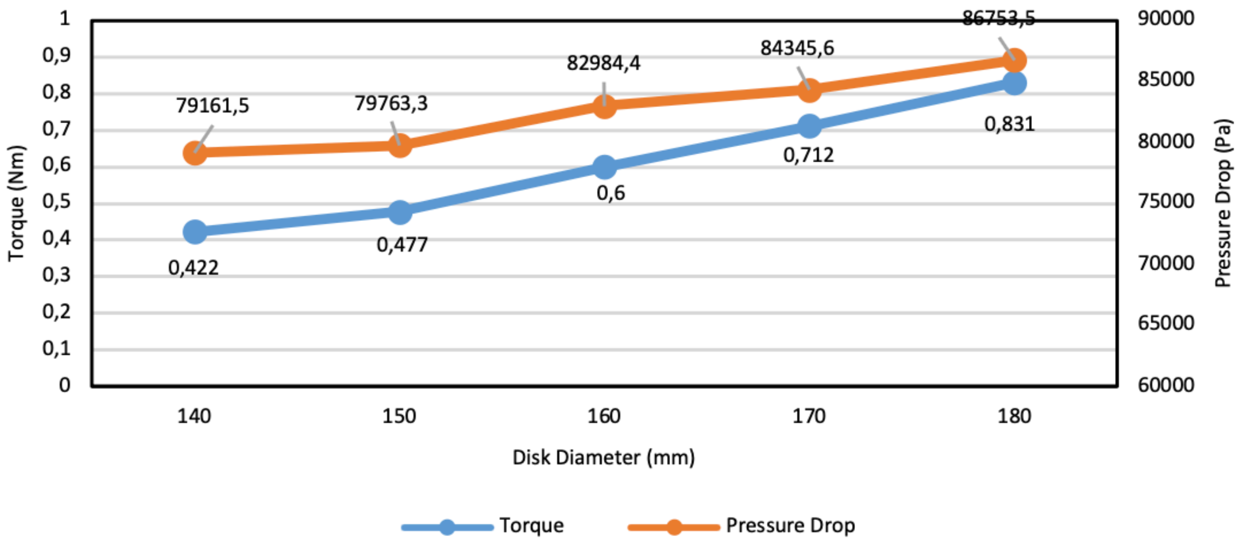

Fig. 7. The relationship of disk diameter to torque and pressure drop

4.4 Relationship of Disk Amount to Torque and Pressure Drop

The input parameter used in the variations in the relationship between the number of disks and this torque is the mass flow rate of the combustion motor exhaust gas. The exhaust gas mass flow rate was measured using maximum engine rotation (1800 rpm). The relationship between the variations in the number of disks against the torque and pressure drop is shown in Figure 8. When each increased the diameter of the disk, the value of torque obtained increased, but not on disks totaling 9, and on disk 9 experienced a significant decrease in torque value. This is because on disks with numbers 5, 6, 7, and 8 still take the pressure from the location of the inlet so that the occurrence of centrifugal force and it can provide a greater torque value, compared to 9 disks; on disk 9, it is classified as too many disks with input provided, resulting in a decrease in the torque value obtained on disk 9.

The pressure drop value on the variation in the number of disks is also shown in Figure 8, where with each increase in the number of disks, the pressure drop value increases. This is because the Tesla turbine applies centrifugal force so that the increasing number of disks makes the fluid take more time to apply pressure on that part of the disk. This is also affected by the number of disks. The higher the number of disks, the higher the pressure drop obtained from the variation in the diameter of the disk. However, not overall, in the variation of nine disks, the pressure drop value decreases. This is because the mass flow inlet value given has not been able to provide good pressure for the variation in the nine disk amounts

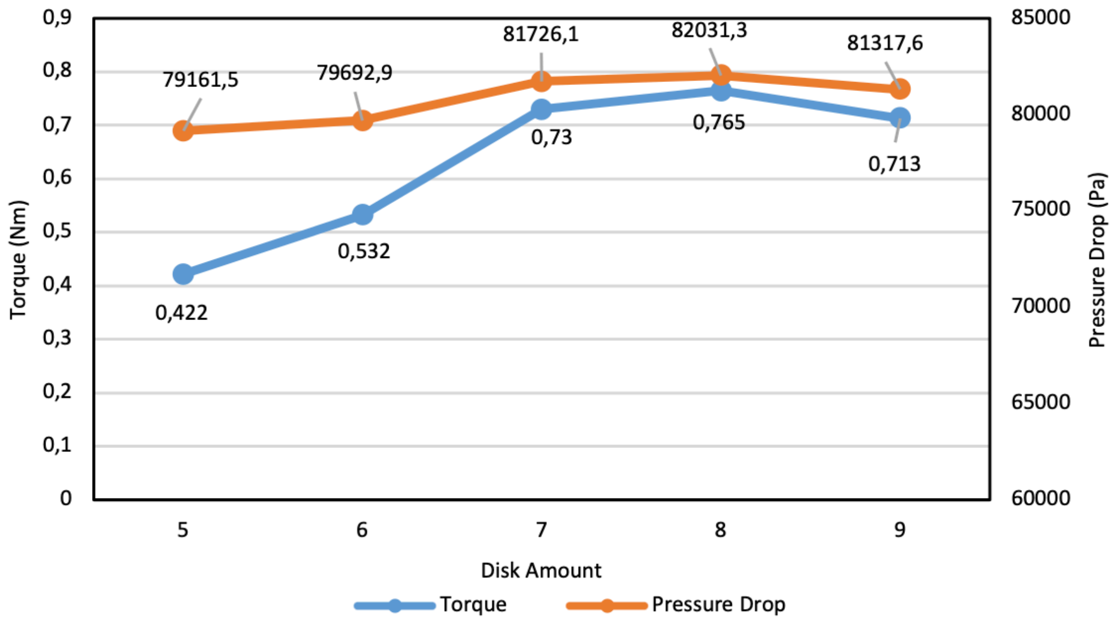

Fig. 8. The relationship of the disk amount to torque and pressure drop

5. Conclusion

After conducting a simulation with variations that were determined for the purpose of the study, the following conclusions were reached:
1. In the relationship between rpm and torque, the highest torque value was found in the rpm variation of 1800 rpm, where the torque obtained was 0.422 Nm.
2. Regarding the relationship between the disk gap and torque, the highest torque value is in the variation with the size of the disk gap of 7 mm, where the torque obtained is 0.54 Nm.
3. The relationship between the disk diameter and torque shows that the highest torque value varies with the size of the disk diameter of 180 mm, where the torque obtained is 0.831 Nm.
4. Regarding the relationship of the number of disks to torque, the highest torque value is in the variation with eight disks, where the torque obtained is 0.765 Nm.
5. The highest pressure drop value is in the relationship of disk diameter to torque with a variation of 180 mm disk diameter, where the pressure drop value obtained was 86753.5 Pa

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