A Literature Review on Principle, Construction and Performance of A Tesla Turbine

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ABSTRACT **Turbomachines are machines that use a rotor and fluid to transmit energy. Transferring from rotor to fluid (known as a compressor) and rotor to fluid (known as a turbine) are two of the most common methods of transferring energy in a turbomachine (called as a turbine). Turbomachines have been around for millennia, and they've evolved into a wide range of diverse designs. In 1913, Nikola Tesla invented a turbomachine that is still in use today. Its design is a little out of the ordinary compared to the current crop of turbomachine designs. It transfers energy from the fluid to the rotor by using the viscous shear force created when a fluid moves between two or more revolving discs. Tesla turbines, as a result, have been widely used in recent years. It may be used to generate electricity and to handle a variety of materials without causing damage to the equipment, among other things. With its viscous shear concept, the Tesla turbine can pump fluids with a broad range of viscosity more effectively. Several factors affect the performance of Tesla machines, including the width and number of discs, the distance between discs, the intake jet angle, the pressure at the inlet, the load, and the Reynolds and Mach numbers. The goal of this article is to provide a comprehensive overview of the last decades' worth of study on the topic at hand. The tesla turbine's design, simulation, and experimental processes are explained in a concise manner. For future study, this document lays out the findings of previous studies, as well as identifying the weaknesses that need to be addressed.**

Keywords: Turbomachine, viscous shear forces, boundary layer, Tesla Turbine, Mach number.

I. INTRODUCTION

Flat plate or boundary layer turbine is another name for the turbine invented by Nikola Tesla in 1913 [1]. Flat and round plates are fastened to a shaft in the plenum chamber of a basic apparatus. The fluid's energy is transmitted to the turbine's rotor when the fluid and the plates contact. Figure 1 is a turbine schematic produced by Tesla as part of his US patent for the device. The shaft serves as a pump or compressor, moving fluid from the centre to the outside edges of the discs when work is applied. Compared to traditional turbines, it has numerous major benefits in that it is simple to make and maintain the turbines. In terms of power to weight ratio, emissions are almost low and noise is decreased. This kind of turbine can operate with a wide variety of operating fluids [2]. Newtonian fluids, non-Newtonian fluids, mixed fluids, particle-laden fluids, two-phase fluids, and so on may all be used in the turbine (many aspects of two-phase flow may be found in Guha [4][5]). Due to the centrifugal forces, the turbine is self-cleaning, allowing it to run on non-conventional fuels like bio-mass or any other solid particle-based fluid in a closed system. [6] If you change the housing and power the rotor from an external source, Tesla turbo-machinery may also function as a compressor. Even more so, it may be used to rotate in any direction. Tesla's disc turbine isn't economically viable due to operational issues and poor efficiency. When a theoretical, analytical and experimental study on modifications of the Tesla turbine sparked attention in the 1950s, the interest in further development of the Tesla turbine was stifled until the 1970s. There are a variety of analytical models, including bulk parameter analysis, truncated series replacement, the integral approach, and finite difference methods, among others. For the Tesla disc turbine, the incompressible flow has been modelled using [12]-[14]. [15] [16] Researchers were able to mimic the flow of these turbines because to recent breakthroughs in computer technology. Due to poor design and lower overall efficiency and large losses in the nozzle, the initial concept was never commercially viable. There is a lot of effort to be done in understanding these losses using well-defined scientific techniques in order to get optimal nozzle and diffuser designs for Tesla turbomachinery.

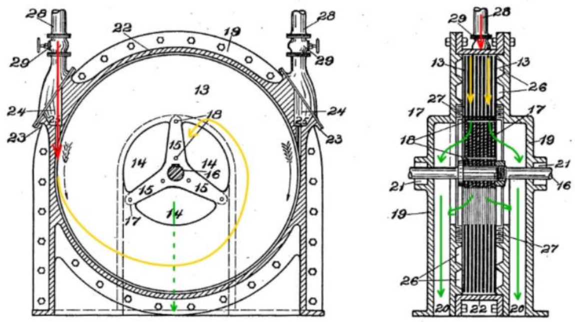


Fig 1. The dual-channel two-way turbine as proposed in the original patent documentation. Red – Fluid inlet at high pressure through the nozzle, Yellow – Fluid path between the rotor blades and Green – Exhaust of low-pressure fluid from the turbine. [1]

As a micro-turbine design, the cheap manufacturing costs and greater performance at high RPMs have made this design practical. It is necessary to increase the efficiency of the initial setup in order for this to occur. As a result, the gas turbine became the primary research focus, and it has now reached a mature level following a series of significant advances. The tesla turbine, on the other hand, is not nearly as well understood. Developing an accurate and complete (but simple enough for practical application in engineering) mathematical theory, say the authors, is a critical first step in understanding the fluid dynamics of the Tesla disc turbine.

It has been attempted by Deam and others. An effort is being made to build simple analytical models for the flow configurations described by Lemma et al. [17] Since the fluid does not flow via a uniform-cross-section conduit as assumed in their theory, this endeavour did not achieve optimum no-loss efficiency in the turbine. [18] When the rotor's speed matches the flow rate, the efficiency is said to be at its highest possible level with no loss. It is true that the lack of rotor-fluid velocity relation does not result in the requisite viscous drag force and so no power is produced.

A. Patented Tesla-Turbomachinery Designs

Inventor Nikola Tesla's invention for a disc turbine in 1913 revolutionised the Turbomachinery industry, resulting in a flood of other ideas for disc turbines that were later patented. Despite the fact that this was a ground-breaking invention, it was only in the 1950s that people began to take notice. To transmit energy from the disc to the fluid, Nikola Tesla's patented design makes advantage of the fluid's natural flow route. As opposed to more traditional designs, this one is said to be more efficient, simpler, and more cost-effective. Conventional designs had substantial losses owing to the rapid shift in the direction of the fluid, and the Disk turbine design avoids this loss to provide an efficient model for transferring energy between fluid and turbine.

It's claimed that a "gas regeneration Tesla-type turbine" patent [35][38] by brothers Robert and Eli Oklejas adds a secondary regeneration system in tandem with an external regenerator, making it more compact than Tesla's original design. Using several stages, Marynowski et al. [28] claim to have improved the tesla turbine concept in 1980 with their invention for a radially staged drag turbine, which is intended for applications requiring numerous stages in order to operate at high efficiency.

In the same year, Fonda-Bonardi was awarded a patent for a "fluid injection control system." As an alternative to adjusting the nozzle's angle of attack or introducing turbulence, this kind of control may be used to manage the volume of fluid entering a disc-type turbine. The vaneless fluid impeller with variable inter-disk spacing was patented by Effenberger [21] in 1983. As one advances away from the axis of rotation, the distance between the discs either reduces or rises, depending on the kinematic viscosity of the fluid.

Inventors Joseph F. Pinkerton and David B. Clifton [39] came up with the idea for a fuel cell or uninterruptible power supply in the year 2000. (Uninterruptible Power Supply). As a result of his efforts in 2001, Entrican, Jr. [26] was granted a patent for an innovative Disk Turbine design that incorporates expansion and adhesion blades in addition to the blade faces. In 2002, Guy Louis Letourneau [30] improved the connection between the disc set and the rotor shaft by inventing the Tesla turbine's Rotor Assembly. Mark S. Vreeke and Viren H. Kapadia devised the Tesla turbine [36], a micro-scale power generating device, while Danial Christopher Dial [32] developed techniques for harnessing the kinetic energy of flowing fluids to generate electricity.

O'hearen and Letourneau secured patents in 2003 for designing the radial turbine blade system and the design for inlet geometry for the disc turbines, respectively, to introduce the fluid into them. When it comes to fluid-to-disk contact, this turbine blade system employs a smooth runner for the purpose. The intake shape adjustment enables the turbine to reach operational speeds from a stop or a very low rotating speed, which is a significant benefit.

One of the most important inventions of 2005 was a patent by Salvatore E. Grande and David R. Draper [21] that provides an axial thrust idea for a turbine that may be employed in a variety of propulsion systems. Continuous and/or impulse combustion turbine technology was enhanced by Kenneth Hicks' [29] patent in the same year. Adhesion and viscosity are key concepts in the design, which works with a variety of fluids. Ceramic and catalytic coatings were also a major focus for him.

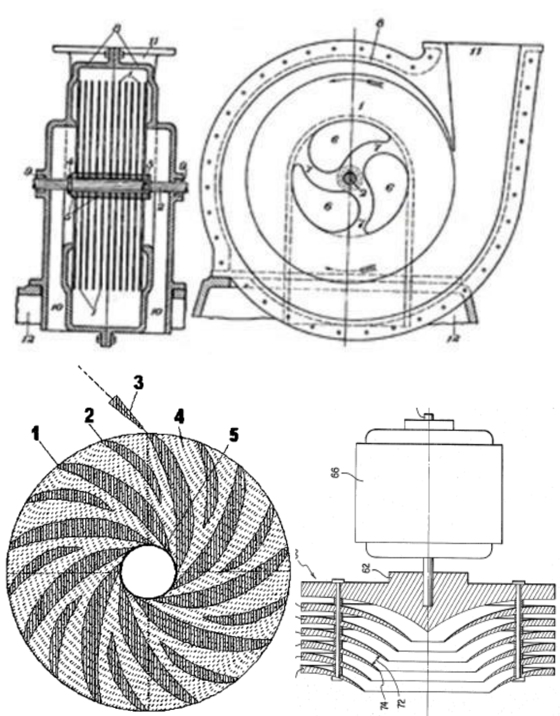
This improved version of the original Tesla bladeless turbine was developed by Christopher Brewer and Lavina [24] in 2006 and was granted a patent in 2007. An end cap completely seals the base of a hollow conical rotor, making this a simple and adaptable design. Improved bracket/spacer geometry in the 2007 patent by Erich A. Wilson [31] on optimising bladeless turbine enhances the efficiency of energy extraction from working fluid and discs.

The effective conversion of wind energy into mechanical effort is shown in the Howard J. Fuller (2008) [34] patent. The airfoil-shaped spacers utilised in this design define a chord that extends toward the rotors' centre. It wasn't until the same year as Couto's invention that Julio Cesar Batista [33] came up with the idea of using Pelton type discs instead of smooth ones, which is what they're named for. When compared to the original design, this form of the disc increases the torque generated in the turbine.

An exhaust section of a steam-powered disc turbine engine was the subject of John W. Detch [37]'s patent application in 2009. To make it more efficient, it uses a modified version of Tesla's turbine design with a closed hub at the top and a horizontally oriented disc stack. Vanes with a tapered cross-sectional form are used, with the solid region at the hub's apex serving as the starting point for the taper. When Takeo S. Saitoh [23] patented the concept of a centrifugal reverse flow disc turbine prime mover in 2010, he was the first to do so. The working fluid is transported via a network of radially etched channels from openings located axially near the turbine shaft. When Robert Fleming [27] came up with the idea of using the Tesla turbine as a hybrid electric power motor and vehicle, it was the same year. As the name implies, it's a car powered by a Tesla turbine.

B. Constructional Features

After the first Tesla turbine design was granted a patent, numerous distinct variations of the same concept were submitted and subsequently granted further patents. The original Tesla turbine [19], the Radial Turbine Blade System [20], the Viscosity Impeller [21], the Bladeless Conical radial Turbine [22], the Centrifugal Reverse Flow Disk Turbine [23], and the Hybrid Tesla-Pelton Wheel Turbine Design [33] are some of the famous designs of these turbines. Figure 2 illustrates the most important aspects of these designs' structure that may be found. It is clear from looking at the images that the fundamental building block of a Tesla turbine is a rotor, onto which a sequence of discs are placed, and spacers are used to keep the discs apart from one another. The rotor, which has the discs installed on it, is contained inside a stator that has an array of nozzles fastened on the surface of it. These nozzles are what feed the working fluid to the rotor.



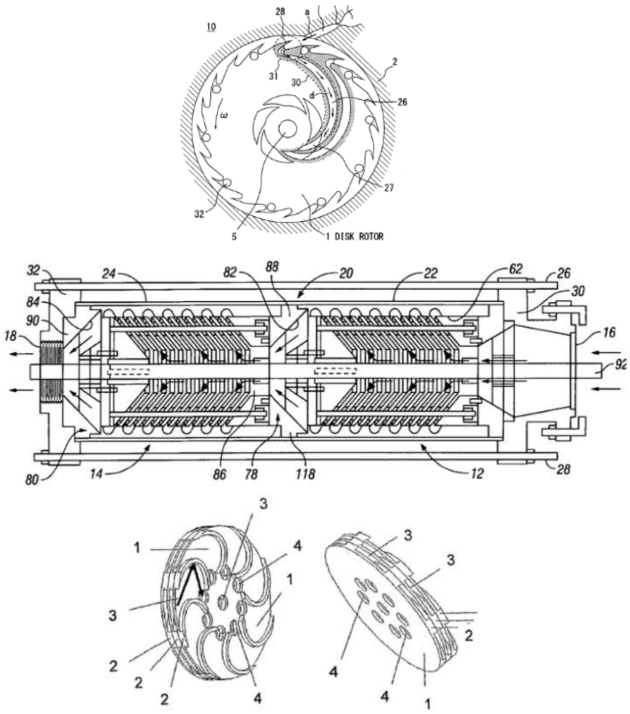


Fig 2. Constructional features of a few Tesla-type turbomachinery designs. (a) The original Tesla design [18] (b) Radial Turbine Blade System [19] (c) Viscosity impeller design [20] (d) Bladeless conical radial turbine [21] (e) Centrifugal Reverse Flow Disk Turbine [22] (f) Hybrid Tesla-Pelton Wheel turbine [32]

C. Performance Parameters and Design Analysis

Since Tesla's initial patented design in 1913, some researchers have suggested modifications to the original Tesla turbine design, while others have shown interest in modelling and numerical simulation studies targeted at improving Tesla turbines' performance. The performance and efficiency of the Tesla turbo-machinery have been the subject of several studies. As a result, most of these studies had a restricted applicability, in terms of both size and speed and the nature of the working fluid, which was the primary goal. The generalised performance of Tesla-type turbomachines has been the subject of various studies. Researchers have discovered that the rotor's efficiency can be at least as great as that of conventional rotors. However, effective nozzles for turbines and diffusers for pumps and compressors have proven challenging to create. This has resulted in relatively moderate levels of machine efficiency. The Tesla-type turbo-machinery has been underutilised primarily for these reasons. In the future, it is expected to be used in circumstances where traditional turbomachinery is inadequate, according to general consensus.

Tesla turbines and traditional bladed turbines are shown in Figure 3. Each has a point beyond which a switchover occurs, and it can be observed that one does the opposite of the other. While traditional bladed designs are superior when larger output power is required, Tesla turbines have been proven to be more efficient at lesser power outputs.

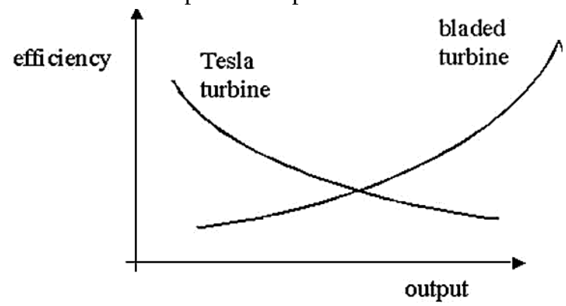


Fig 3. Graph showing the performance of the Tesla turbine

It has been discovered that the performance and efficiency of the rotor of Tesla type turbomachinery are reliant not only on the parameters linked to the rotor assembly, but also on the efficiency of the nozzles and the interaction between the nozzles and the rotor. The performance of the pump is also heavily reliant on the interaction between the fluid that is leaving the rotor and the fluid that is in the volute, as well as the effectiveness of the diffusion that occurs in the volute.

The behaviour of Tesla-type turbomachinery, under the impact of the parameters indicated previously, has been revealed using a variety of analytical approaches, in addition to the physical testing processes that have been applied. The growth and accessibility of computers have led to an increase in the usage of facility simulation studies, which are being used to a large extent in order to get a better understanding of the behaviour of these equipment. The paragraph that follows presents many different approaches to design analysis that were used.

Construction and experimental research on low-pressure heads for micro Tesla turbines were described by Vedavalli G. Krishnan et al. [40]. With a flow rate of 2 cc/sec and a stack of 13 disc rotors, they claimed an efficiency of 36%. To investigate the constant flow of an incompressible fluid between two parallel discs spinning in sync, Milan Batista [41] devised an analytical solution to the Navier Stokes equations. Research by Poncet et al. [42], utilising both experimental and computational approaches, looked at the onset of turbulence in rotor-stator flows in an annular hollow. We also provide a contrast between the DNS findings and the flow visualisation.

For the purpose of modelling and optimising axial turbines, Ning Wei [43] looked into the relevance of loss models and their applications. Adding the author's own film cooling loss approach as a secondary factor in the loss models improved the reliability of turbine performance predictions. According to research by Jessica Gissella and coworkers [44], the most efficient design is a disc with embossed airfoil impressions around the rim. Cros and LeGal [45] used visualisation and video image analysis to study the transition to turbulence in a flow bounded by a stationary and a spinning disc.

Micro air vehicles with flapping wing mechanisms are the focus of Tim van Wageningen's [46] research, which included the use of finite element models to determine and optimise the size of a hydrogen peroxide-powered engine. Computational fluid dynamics (CFD) simulations of many models of Tesla turbines were performed by Piotr Lampart and coworkers [47] using ANSYS Fluent and the RANS model, which was complemented with the K- SST turbulence model. The issue of flow via a radial diffuser was solved by Jose Luiz Gaschem et al. [48] using the immersed boundary approach in conjunction with the virtual physical model for complex geometries. CFD techniques were used by Peter Harwood [49] throughout the Tesla turbine's design and analysis phases. S. Viazzo, S. Poncet, and colleagues [50] describe using two independent LES programmes to model turbulent flow in a covered rotor-stator cavity. The first method of LES uses a three-dimensional spectral coding coupled with a spectral vanishing viscosity model. In contrast, the second LES method uses a dynamic subgrid model in tandem with a compact finite difference code of the fourth order. Utilizing ANSYS Fluent, C. J. Deschamps [51] simulated fluid dynamics using flow transfer equations. Following that, he used an axial turbine model to investigate turbulence in the flow. P. Sandilya and coworkers [49] combined physical modelling with tests and compared their findings to those from analytical models. Specifically, the Crank-Nicolson semi-implicit formulation was utilised to discretize the underlying differential equations. The laminar flow between two spinning parallel discs was studied by Shuichi Torii [52] using ANSYS Fluent to examine the thermal-fluid transport processes involved.

II. INFLUENCE OF OPERATIONAL PARAMETERS ON PERFORMANCE

The Tesla turbine, often known as the multi-disc turbine, was patented by N. Tesla in 1913 [1]. However, as can be seen in Figure 4, the Tesla turbine (TT) has recently been the focus of study, despite having received very little attention since its inception. Between 2000 and 2010, more than 90% of research on TT were published. (Darkened zone) Greater equipment losses when looked at as a turbine for large producing power plants (on a large scale) [2] may have contributed to the field's relative neglect until the 2000s.

Recently rising research activity may be attributed to the growing need for low-power energy-efficiency technologies. An early analytical analysis of TT showed promise for using the technology in residential-sized turbines [3][4][5]. I low output power ORC [2][6][7][8][9]; (ii) energy harvesting [10][11][12][13]; and (iii) micro-cogeneration with low energy availability gases/streams are all examples of possible uses for this equipment [14][15][16][17][18].

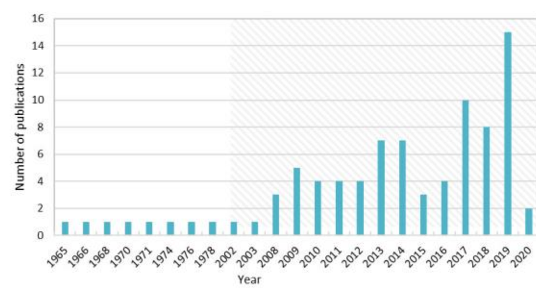


Fig 4. Number of publications per year on Tesla turbine since 1964 (years without publications were suppressed)

Scopus® and Web of Science (WoS) databases, which are representative scientific databases in the engineering area, were used to conduct a bibliometric and content analysis of research and conference papers to assess the current state of the art in TT research [19,20]. The following query string was used: THE WHOLE BUNCH ("Tesla turbine*" OR "Bladeless turbine*" OR "Multiple Dis* turbine*" OR "Viscous turbine*"). Scopus returned 301 results, whereas WoS only returned 65. After filtering and preliminary reading, 86 articles were selected for a content analysis. The main findings and the driving research question are presented here. The complete bibliometric analysis and additional content analysis data are available in the APPENDIX.

To see how the 86 selected publications cover different approaches to tackling problems, see Figure 5. Analytical methods for modelling TT behaviour received the most attention (45 papers), followed by experimental (39) and CFD (38) methods. Two articles were offered for perusal [21,22].

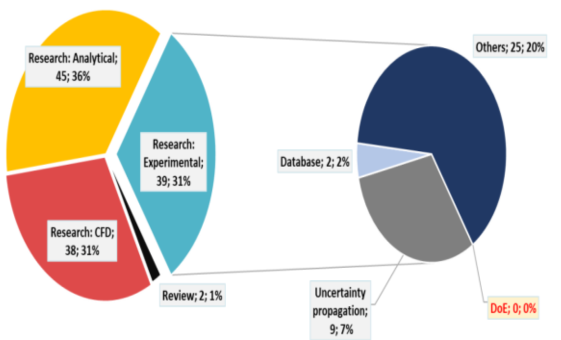


Fig 5. Type of studies on Tesla turbine: a) problem-solving approaches and b) quality analysis of experimental studies.

Although most of the articles are theoretical (67%), it was found that the experimental ones were often used to evaluate innovative analytical and CFD solutions, especially the work detailed by Rice [3, which was the most referred paper]. Therefore, a more in-depth analysis of the experimental results was conducted (Figure 5.b) to determine the makeup of the available data based on the presence of: I uncertainty propagation analysis (9); (ii) a database that presents efficiency, power, mass flow rate, and thermodynamics states at the inlet and outlet of the turbine (2); and (iii) a statistical analysis, such as Design of Experiments DoE. No uncertainty propagation analysis was performed, and no Design of Experiments (DoE) principles were used, in the vast majority (25) of the studies that were cited. Figure 6 is a performance map illustrating how most papers we reviewed used turbine performance metrics such as efficiency and output power to characterise turbine behaviour.

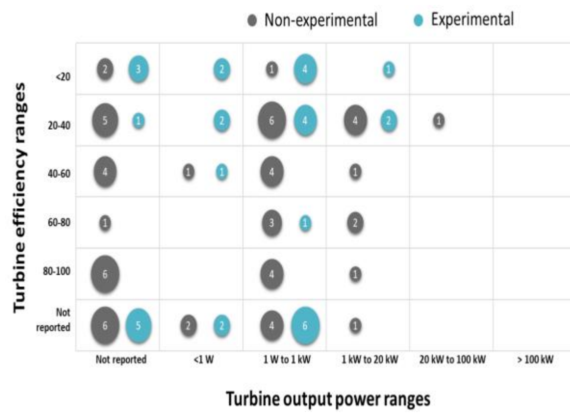


Figure 6 – Tesla turbine performance map (efficiency vs output power). Circle diameter indicates the number of papers on both power and efficiency; the circle color indicates the problem-solving approach.

As can be seen in Figure 6, almost all figures purported to represent output power were found to be less than 20 kW. The greatest power output from an experiment was reported by Rice [3] to be 4 kW for bench equipment. The sub-watt scale has been the focus of a significant amount of experimental investigations (10 of 60 published values), but only a small number of computational fluid dynamics and analytical methodologies (3 of 60 values). These findings provide evidence in favour of using TT as a microturbine and draw attention to the growing interest in employing it as a sub-watt energy collector. Taken as a whole, the TT efficiency values vary from 20% to 40% (25 of the 67 values), with 13% of the values falling below that threshold. TT performance numbers are not exact for determining the equipment's maximum efficiency, especially when compared to data from analytical or CFD methods. 10 of the efficiency values in the experimental works are below 20%, while 9 are between 20% and 40%. Non-experimental work efficiency values indicate a more balanced range, with 16 values ranging from 20% to 40%, 11 values over 80%, and 10 values ranging from 40% to 60%. This data dispersion may explain the recent increase in the number of papers since TT efficiency is still poorly known. Efficiency in TT may be defined in a variety of ways. Figure 7 shows the results of a statistical analysis of the most popular mental models.

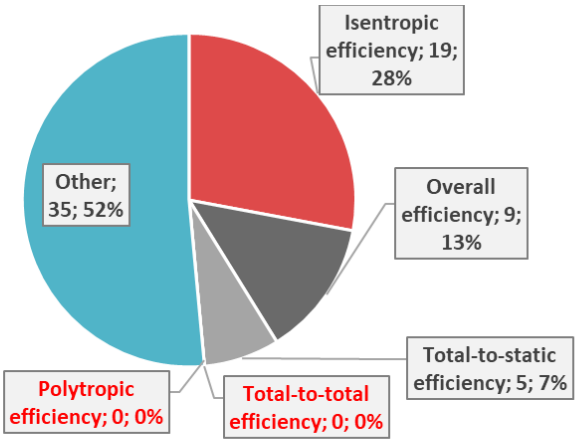


Figure 7 – Distribution of reported efficiency according to its physical definition.

The lack of agreement on the reported statistics of TT efficiency may be partially attributed to the many ways in which it is defined. Most of the research didn't define efficiency in terms of its physical manifestation (35 out of 69 publications). Since there is no agreement definition, like that supplied for gas turbines, Sengupta and Guha [23] caution against relying on TT efficiency numbers. Highest efficiencies stated by experimental investigations may vary widely; this may be due to sloppy experimentation. The necessity for a broader approach to the problem was highlighted with the help of the SLR.

III. CONCLUSIONS

The Tesla turbomachinery, which functions as a turbine, compressor, and pump, is appropriate for scenarios requiring compacted units to produce power, carry goods, or pump fluids, such as in isolated locations. Tesla machines, as a unique source of rotational motion of this kind, may operate with a wide variety of fuels and fluids. In most circumstances, conventional turbomachinery will beat Tesla-type turbomachinery in terms of efficiency and performance. As a result, it cannot be expected to replace ordinary water pumps or gas turbines of the same kind. Tesla-type turbomachinery may serve as a benchmark in circumstances when regular machines are inadequate. Applications requiring minuscule shaft power or the use of non-Newtonian fluids, for example, are covered. Multiple disc turbomachines may operate in abrasive two-phase flow mixtures with less material erosion from the rotor than single disc turbomachines. Researchers revealed that the efficiency of the rotor may be at least as high as that of conventional rotors. Efficient nozzles for turbines have been difficult to develop, and efficient diffusion for pumps and compressors has been much more challenging. As a consequence, machine efficiency has been rather modest. For these reasons, Tesla-type turbomachinery has been underutilised. According to popular opinion, it will be employed in situations when regular turbomachinery is insufficient in the future.

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