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# Preliminary Test of Friction disk type turbine for S-$CO_2$ cycle application

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## 1. Introduction

Among the next generation reactors, a sodium-cooled fast reactor (SFR) has received worldwide attention. To develop safe and highly efficient system, the supercritical carbon dioxide (S-$CO_2$) Brayton cycle has been suggested as the power conversion system [1].

Due to the relatively mild sodium-$CO_2$ interaction, the S-$CO_2$ Brayton cycle can reduce the accident consequence compared to the steam Rankine cycle. Also the S-$CO_2$ power conversion cycle can achieve high efficiency for SFR core thermal condition. Moreover, the S-$CO_2$ power cycle can reduce the total cycle footprint due to high density of the working fluid.

However, the high pressure operating condition and low viscosity of the fluid cause difficulties in designing appropriate seals and multi-stage turbo machineries. To solve the problem for designing turbo machineries in a creative way, KAIST research team tested a friction disk type turbine concept for the S-$CO_2$ cycle application. In this paper, the investigation of the Tesla turbine and preliminary test results with compressed air are covered.

## 2. Investigation of Friction Disk Type Turbine and Test Facility

### *2.1 Friction Disk Type Turbine*

The Tesla turbine is a unique concept of friction disk type turbo machinery, which was designed by Nikola Tesla [2]. The bladeless Tesla turbine uses only a friction forces to rotate the disc, which is connected to the generator shaft.

Table I: Comparison of turbine characteristics

| | Conventional Turbine | Tesla Turbine |
|---|---|---|
| Characteristics | Blade type | Blade less, disc type |
| | Impulse & reaction | Friction force |
| | Well experienced, optimized | Low Pressure ratio (S-$CO_2$ cycle) |
| | Need high quality clearance | Easy Manufacturing , modularized design |
| | No phase change allowed | Robust - Two phase, Sludge flow |
| | Maintenance Difficulties | Easy maintenance |

The typical characteristic of the conventional turbine and the Tesla turbine are tabulated in Table I. Well experienced conventional turbines such as a steam turbine or a gas turbine, use series of blades to interact with fluid flow. While the mechanical efficiency is maximized, the blade type turbine has limitations on the operating condition and fluid quality.

However, the Tesla turbine can have less concerns of fluid quality or impurities due to the bladeless disc. So, the KAIST research team investigated a Tesla turbine for S-$CO_2$ cycle application. Since the S-$CO_2$ cycle can be operated in various fluid conditions including phase change, the Tesla turbine can be an option.

The reverse operation of the turbine can be utilized for the pump application. Thus, the friction force can be major mechanism for robust and stable S-$CO_2$ power conversion system.

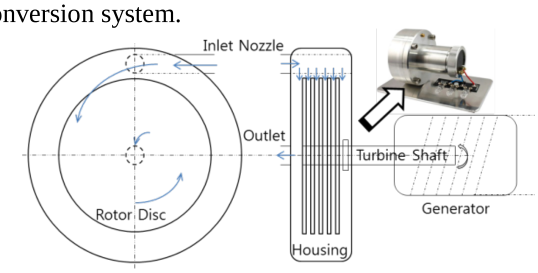


Fig. 1. Schematic Diagram of Tesla Turbine

To test a friction disk type turbine, lab-scale Tesla turbine was first investigated. The figure of the Tesla turbine and the schematic diagram are shown in Fig. 1. For the rotating disk, 7.3mm diameter, 1mm thick steel plate is used. Total five disks are aligned together with 1mm gap for a flow channel.

The Tesla turbine has been investigated with compressed air at 0.8MPa, and the preliminary test data is shown in Fig. 2. As shown in the graph, rotating speed and electric power generation is related with flowrate. To understand the mechanical characteristic of Tesla turbine, more investigation will be followed.

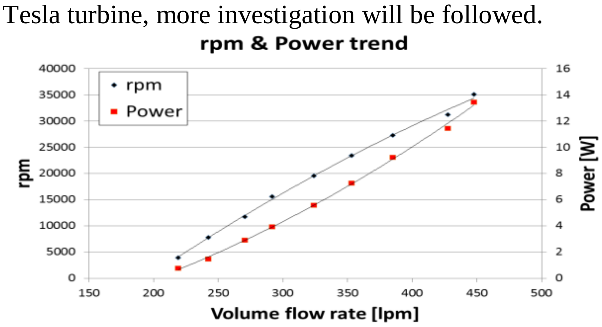


Fig. 2. Preliminary test result of Tesla turbine

### *2.2 Specification of Test Facility*

The KAIST S-$CO_2$ research team has conducted various researches to utilize the benefits of the S-$CO_2$ Brayton cycle. To explore the non-linear fluid characteristic of the $CO_2$ near the critical point (30.98℃, 7.38MPa), S-$CO_2$ pressurizing experiment (S-$CO_2$PE) facility was constructed. From the component performance test experiences under S-$CO_2$ condition, compressor and heat exchanger design methodologies were developed [3-4].

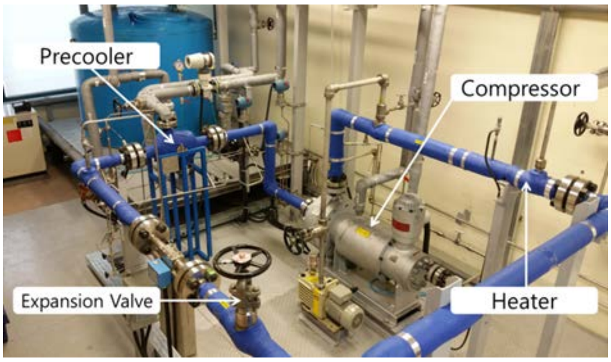


Fig. 3. Overall view of the S-$CO_2$PE facility.

As shown in Fig. 3, the S-$CO_2$PE facility consists of four parts to demonstrate S-$CO_2$ simple Brayton cycle. For the compressor, 26kW seal-less canned motor pump is used for pressurization and circulation. The compact heat exchanger PCHE is used for the pre-cooler. For the heating and expansion process, electric band type heater and globe valve is used respectively.

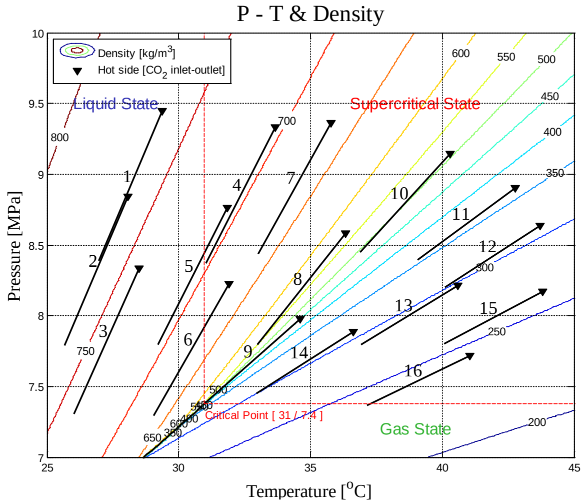


Fig. 4. Pressurization ability of S-$CO_2$PE facility

To conduct a turbine test under various $CO_2$ conditions, the pressurization ability of the existing S-$CO_2$PE facility was investigated. At liquid state, the pressure ratio is higher than the gas or supercritical state due to the lower compressibility factor. Nevertheless, it is important to obtain large pressure differences for turbine performance, gas condition was chosen for the test. Since the gas state can achieve high turbine inlet temperature by avoiding pseudo-critical line during the heating process.

With the successful experiment, the S-$CO_2$PE facility may form simple Brayton cycle, as shown in Fig. 5.

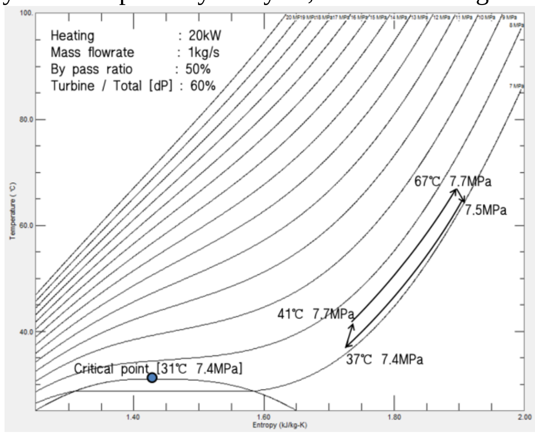


Fig. 5. T-S diagram of target test condition

### *2.3 Tested Friction Disk Type Turbine*

The S-$CO_2$ Brayton cycle operates at over critical pressure of the $CO_2$ (7.38MPa). Due to the high pressure operating condition, the tested Tesla turbine is required to be contained in a high pressure vessel. As shown in Fig. 6, 6L (148ϕ) pressure vessel was manufactured. The pressure vessel is made of stainless still 304 and the vessel can endure 13MPa at 100℃.

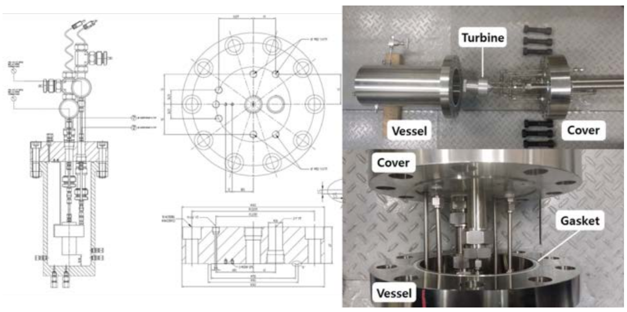


Fig. 5. Design drawings and feature of pressure vessel for Tesla turbine test

The test facility modification is planned to make a turbine test section, and the manufactured pressure vessel will be connected at expansion part in parallel to bypass the main flow. The test will be conducted under supercritical and liquid, gas states by controlling the load of the turbine.

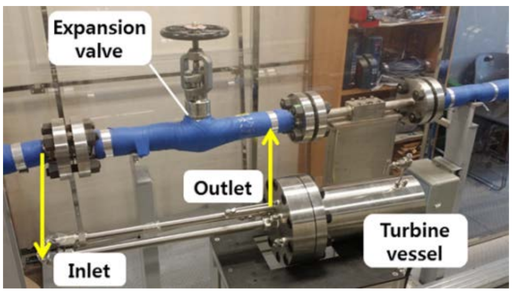


Fig. 6. Planned Tesla turbine test configuration of S-$CO_2$PE

facility.

## 3. Conclusions and Further works

The KAIST research team investigated a friction disk type turbine, named as Tesla turbine, for the S-$CO_2$ power cycle applications. Due to the robust design of the fiction disk type, the Tesla turbine technology can be utilized not only for S-$CO_2$ turbo machinery but also for the multi-phase or sludge flow turbo machinery.

The preliminary test of lab-scale Tesla turbine with compressed air was conducted. The high pressure vessel was manufactured for the S-$CO_2$ operating condition. The test will be concentrated on the turbine efficiency measurement under various conditions and development of the design methodology.

After developing the design methodology, the design optimization will be conducted by changing design variables. The applicability of the friction disk type turbine for the S-$CO_2$ power cycle will be covered in presentation with preliminary test data.

## ACKNOWLEDGEMENT

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