Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Preliminary study of Friction disk type turbine for S-CO_2 cycle application

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1. Introduction

Recently, a highly efficient and safe nuclear power system has received worldwide attention due to the rising energy demand and global warming issues. Among the next generation reactors, a sodium-cooled fast reactor (SFR) with the supercritical carbon dioxide (S-CO_2) Brayton cycle has been suggested as the advanced energy solution [1].

The S-CO_2 power conversion system can achieve high efficiency with the SFR core thermal condition (450~550℃) and also can reduce the total cycle footprint due to high density of the working fluid. Moreover, the S-CO_2 power cycle can reduce the accident consequence compared to the steam Rankine cycle due to the mild sodium-CO_2 interaction.

The S-CO_2 power cycle has different characteristic compare to the conventional steam Rankine cycle or gas Brayton cycle. For the turbine section, the expansion ratio is much smaller than the other cycles. Thus, different type of turbine should be evaluated for the advanced S-CO_2 technology and the KAIST research team considered a friction disk type turbine (Tesla turbine) concept for the S-CO_2 cycle applications.

In this paper, the test result and analysis of a lab-scale Tesla turbine in the KAIST S-CO_2 experimental facility (S-CO_2PE) are briefly discussed.

2. Description of Friction Disk Type Turbine and Test Facility

2.1 Friction Disk Type Turbine and Air driven test results

The friction disk type turbine is a unique concept of turbo-machinery, which was designed by Nikola Tesla [2]. The major mechanism of the Tesla turbine is shear stress of the fluid.

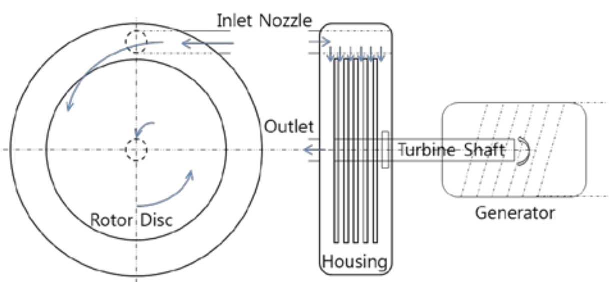

Fig. 1. Schematic Diagram of Tesla Turbine

As described in the figure, the bladeless Tesla turbine uses only a friction forces to rotate the disc, which is connected to the generator shaft.

Table II: Comparison of the 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 Tesla turbine compared to the conventional turbine are tabulated in Table II. The advantages of the Tesla turbine are easy manufacturing and maintenance due to the simple bladeless design. Also, due to the bladeless design, the Tesla turbine can be operated under low fluid quality conditions without concern of blade surface erosion. To test a Tesla turbine under S-CO_2 condition, lab-scale Tesla turbine was installed in the external pressure vessel. The tested Tesla turbine is summarized in the Fig. 2 and Table III.

Table III: Descriptions of tested Tesla turbine

Sizes	Turbine housing diameter [mm]	100
	Turbine housing length [mm]	120.75
	Disc diameter [mm]	78
	Disc thickness [mm]	1.2
	Disc gap [mm]	1.5
	Number of discs	5
Materials	Housing	6082 aluminum
	Shaft	303 stainless steel
	Disc & spacer	6082 aluminum
	Nozzle	CZ121 brass
	Type	3 Phase AC
Generator	Maximum output [W]	150
Bearing	Type	Ceramic ball bearing

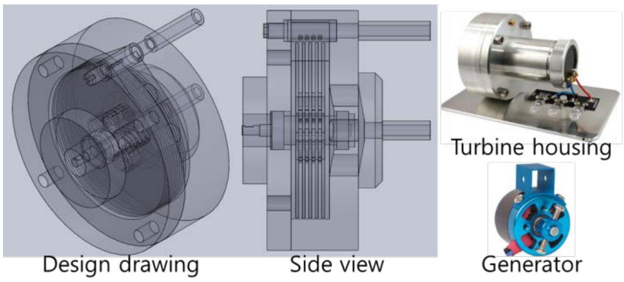

Fig. 2. Design drawings and picture of tested Tesla turbine

2.2 Description of Experimental Facility

To explore the non-linear fluid characteristic of the CO_2 near the critical point (30.98℃, 7.38MPa), a S-CO_2 pressurizing experiment (S-CO_2PE) facility was constructed. From the component performance test experiences under S-CO_2 condition, compressor and heat exchanger design methodologies were developed [3-4].

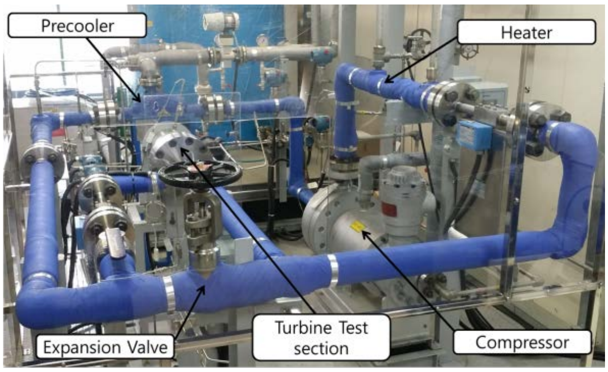

Fig. 3. View of the S-CO_2PE facility.

As shown in Fig. 3, the S-CO_2PE facility consists of four parts to demonstrate a 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 are used respectively.

3. Experimental result of the Tesla Turbine

3.1 Air driven test results

Before the Tesla turbine performance test under S-CO_2 condition, a preliminary test for nozzle angle and bearing performances are conducted. Also the turbine generator (150W) is tested. The generated power will be analyzed to obtain the shaft power and rotational speed information due to the direct measurement limitation of the test section.

At first, a Tesla turbine was tested with compressed air (5-7bar) under ambient condition for the generator test. From Fig. 3 measurement result, synchronous coefficient C was obtained.

$$\text{rpm} = \text{C} * \text{Hz(Electricity signal)}, \; C = 8.5714 \qquad (1)$$

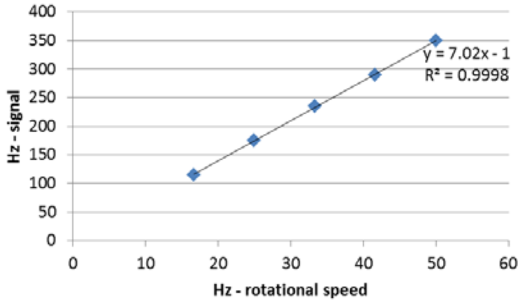

Fig. 4. Preliminary generator test result

The optimum angle of the inlet nozzle was identified with the air driven test results. As shown in Fig 5, the optimum angle was identical to the tangential direction of the disc tip.

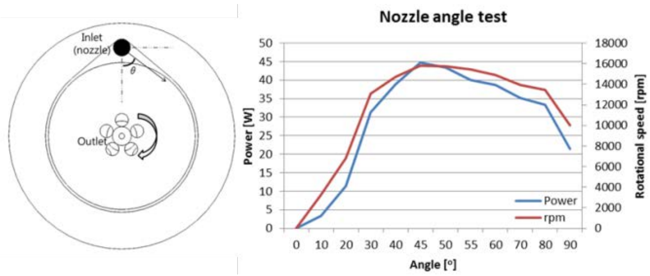

Fig. 5. Preliminary air driven test result with different nozzle angle

The original bearing of the tested Tesla turbine was greased radial ball bearing. However, especially the supercritical state of CO_2 fluid may dissolve oil lubricant, the conventional oil lubricated bearings are not suitable for the S-CO_2 environment. As an alternative way, a ceramic ball bearing is applied. Generally the ceramic ball bearing can be operated at high temperature, high speed without lubricant.

In Fig. 6, the performances of the greased, degreased and ceramic ball bearings are compared. The results showed that higher pressure load makes higher flowrate and higher power generation as expected. The greased ball bearing performance decreases in 20% when the grease is lost. The ceramic ball bearing showed 2.5 times higher power generation with higher rotational speed.

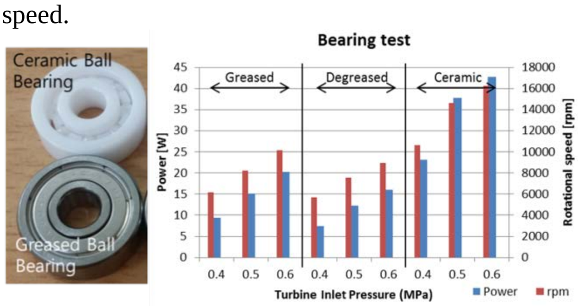

Fig. 6. Preliminary air driven different bearing test results

3.2 S-CO_2 test results

As described in section 2, the pre-existing S-CO_2PE facility was modified to conduct a Tesla turbine performance test. With the best performing bearing and nozzle angle, Tesla turbine was tested under various CO_2 conditions. The following figure shows the tested conditions. The electricity was successfully generated with the experimental facility and the tested data are summarized in Table IV.

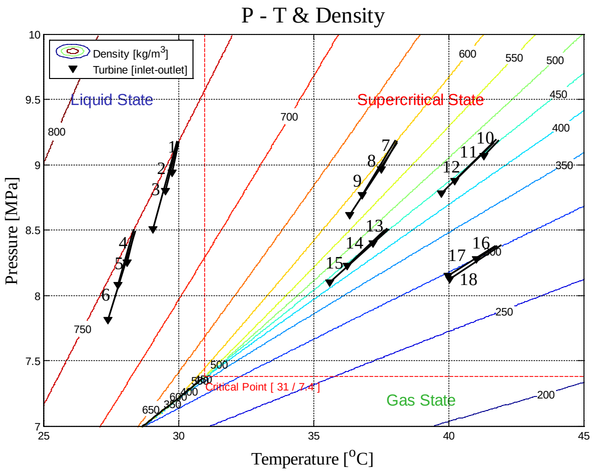

Fig. 7. S-CO_2 Tesla turbine test case and inlet to outlet conditions

Table IV: Descriptions of tested Tesla turbine

Case	Mdot	P_isen	P_elec	rpm	eff
	[kg/s]	[W]	[W]	[rev/m]	[-]
a-1	0.17	53.52	0.58	1206	1.08
a-2	0.22	112.95	1.16	1757	1.02
a-3	0.30	273.35	2.31	2631	0.84
b-4	0.18	55.55	0.60	1226	1.09
b-5	0.24	135.43	1.38	1937	1.02
b-6	0.30	275.18	2.36	2666	0.86
c-7	0.15	53.76	0.60	1243	1.12
c-8	0.21	146.25	1.58	2109	1.08
c-9	0.24	224.98	2.23	2597	0.99
d-10	0.10	26.45	0.26	806	0.97
d-11	0.16	102.47	1.26	1851	1.23
d-12	0.18	163.16	1.90	2366	1.17
e-13	0.10	25.94	0.26	823	1.02
e-14	0.15	88.61	1.11	1731	1.25
e-15	0.18	162.57	1.95	2391	1.20
f-16	0.08	25.00	0.21	737	0.83
f-17	0.11	86.16	1.13	1740	1.31
f-18	0.12	105.99	1.39	1980	1.31

4. 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.

The preliminary test of a lab-scale Tesla turbine was conducted with compressed air. The generator, nozzle angle and bearing performances are tested. With the best performing nozzle angle and bearing, the Tesla turbine was tested under various S-CO_2 conditions. As a result, the S-CO_2PE facility generated electricity (0.5-5W). The isentropic efficiency was relatively low (0.8-1.3%).

It seemed that, the authors need further study to understand the main mechanism and maximize the efficiency. After developing the design methodology, the design optimization will be conducted to show the applicability of the friction disk type turbine for the S-CO_2 power cycle.

Furthermore the reverse operation of the friction disc turbine can be utilized as compressor applications. In this manner the friction disc turbo machinery need to be studied further.

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