EXPERIMENTAL LOOP S-CO2 SUSEN

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ABSTRACT

Supercritical carbon dioxide (S-CO_2) cycles are very perspective and they are researched globally. The application of this gas medium is fairly wide and it could be find both in the nuclear and non-nuclear power systems. Current research consider S-CO_2 to be a suitable coolant used for the secondary circuits of power plants. The specific studies were made within the framework of the European research project dealing with the Gas-cooled Fast Reactors development. The possible usage of the S-CO_2 in the secondary circuit was studied in order to improve the efficiency of the whole power plant. This type of the research has to be studied and verified using the experimental data. That is the reason why the experimental facilities are needed.

Research Centre Rez deals with this R&D topic in the frame of the SUSEN (Sustainable Energy) project. One of the goals of this project is to build the S-CO_2 experimental loop. This Supercritical carbon dioxide experimental loop was designed and is currently being built. This loop will be useful for material testing, vibration of variously heated channels, wrapping turbine blades, heat-exchangers tests, etc. Heat-exchangers testing depending on the CO_2 purity will be one of the experimental issues. Design parameters of the S-CO_2 loop are defined by:

- max. temperature = 550 °C,
- max. pressure = 25 MPa,
- max. mass flow rate = 0,35 kg/s,
- heating power = 100 kW.

It is possible to modify the current status of the experimental loop using the specific test-section. The loop is being built in the area of Research Centre Rez, close to Prague, capital of Czech Republic. Specific tests could begin in 2016.

INTRODUCTION

The first research of the use of CO_2 cycles appeared in the first half of the 20th century. Interesting properties of CO_2 were identified during this research. Because of imperfections in construction materials the CO_2 cycle has never been tested in practice, despite the broad theoretical research on cycles with supercritical CO_2. With the progress of modern technology, new materials lead to reconsider use of the S-CO_2 in the new reactor's concepts and subsequently in solar and geothermal power plants as well.

Nowadays many institutions in many countries are focused on research of the S-CO_2, either within national or international projects. The research, which is primarily concentrated in the USA at Sandia National Laboratories (SNL) [1] deals with small experimental S-CO_2 loops. Others are at the Massachusetts Institute of Technology (MIT) [2], Argonne National Laboratory (ANL) [3], University of Wisconsin [4], etc. Further research is carried out in Japan at Tokyo Institute of Technology (TIT) [5], where it deals with fast reactors FBR. Research is also carried out in the Czech Republic at the Research Center Rez and the Czech Technical University in Prague [6], [7].

At the Research Center Rez the experimental S-CO_2 loop is designed to study the thermodynamic properties of CO_2, testing of heat exchange under various conditions, study correlation of heat transfer in the supercritical region at different parameters, such as temperature, pressure and flow rate. The material testing is also possible. The operating pressure of the loop is in the range from 12.5 MPa to 25 MPa.

USABILITY OF THE LOOP

One of the biggest issue from the thermal-hydraulic point of view is the heat exchanger. Huge difference in thermal capacity at different pressure levels cause many problems. There is a lot of low-temperature heat which is not possible to use it in simple Brayton cycle with regeneration, because of the pinch point.

Following this reasons, many different cycle designs were developed and studied. S-CO2 loop, which is currently being built in RC Rez allows verification of heat exchange efficiency and validation of used calculations tools under different conditions.

The designed heat exchanger is designed as modular and the surface area of heat exchanger can be easily changed. There are two levels of heat exchanger, low-temperature and high-temperature one.

To be able to study and verify other cycle composition, not only the simple Brayton cycle, there is a by-pass line with the heater. Different mass flow for both sides of low-temperature heat exchanger is possible to set (and study heat transfer in various cycle compositions) using this by-pass line.

DESCRIPTION OF THE EXPERIMENTAL LOOP

Arrangement of the Primary loop is show in Fig.1. The loop primarily consists of a low temperature regenerative heat exchanger (LTR) and high temperature regenerative heat exchanger (HTR), the main pump (MP) and the electric heater H1 of the maximum power 100 kW, which is connected to the test section. For MP frequency converter of maximum power 10 kW is used.

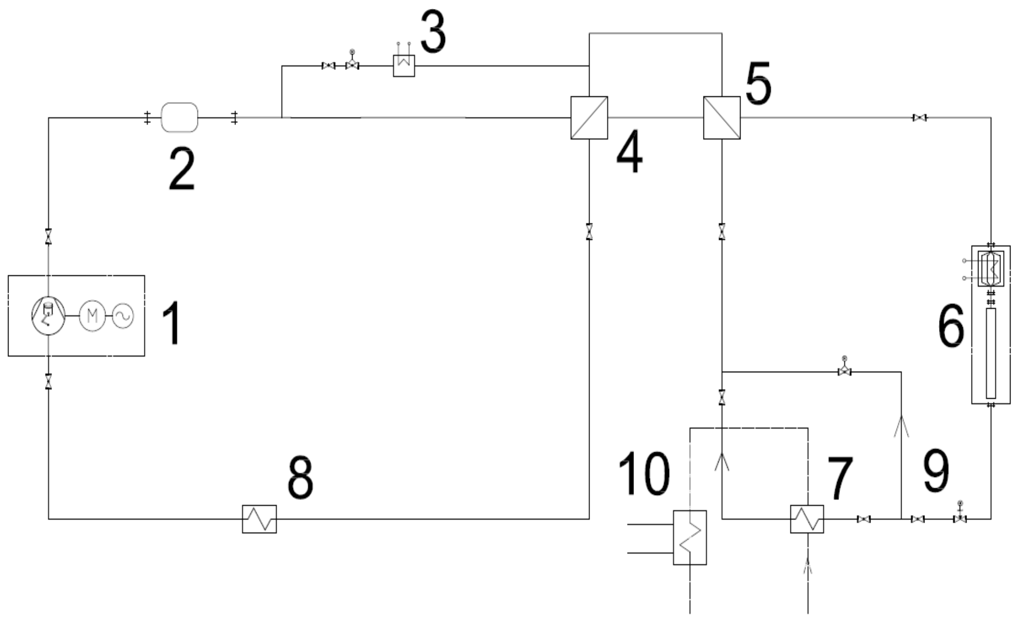

Figure 1. Arrangement of the Primary loop

Description of Fig. 1.

1. Main pump	(MP)
2. Pressure pulse dumper	(PPD)
3. Electric heater 2	(H2)
4. Low temperature recuperator	(LTR)
5. High temperature recuperator	(HTR)
6. Electric heater 1 with test section	(H1, TS)
7. Cooler 2	(CH2)
8. Cooler 1	(CH1)
9. Reduction valve	(RV)
10. Cooler 3	(CH3)

The maximum power of the primary loop and the other installment is 120 kW. When the electric heater H2 is connected the overall power of the primary loop is higher and the overall power of the experimental loop is 150 kW. The electrical heater H2 is connected at the beginning of the primary loop to one of two branches of the MP. H2 is designed to simulate the behavior of circuits for the cases when the temperature is changed at the inlet to the LTR and HTR.

For cooling two coolers CH1 and CH2 are connected to the loop. The cooler CH2 uses as the main cooling medium oil (Marlotherm®SH), because of the high temperatures of the exhaust heat. This heat is also removed through the cooler CH3 into water. Next part of the primary loop is test section with the electric heater H1. Behind TS reduction valve RV is positioned. It is used to simulate the expansion turbine behavior and it is intended to reduce the pressure from 25 to 12.5 MPa.

The other components are key components necessary for proper operation of the loop such as vacuum pump, insurance components, regulation and shut-off valves.

The main operating parameters of the Primary loop are shown in Table 1.

Name	**Value**	**unit**
Maximum operation pressure	25	[MPa]
Maximum pressure in Primary loop	30	[MPa]

Maximum operation temperature	550	[°C]
Maximum temperature in HTR	450	[°C]
Maximum temperature in LTR	300	[°C]
Nominal mass flow	0,35	[kg/s]

Table 1. The main operating parameters of the Primary loop

Cooling water circuit is used for heat removal from the coolers CH1 and CH3 in the primary loop. For cooler CH3 heat is removed via the intermediate circuit using oil cooler CH2. In addition, it is used for cooling the MP. The main operating parameters for the Cooling water circuit are shown in Table 2.

Name	Value	unit
Maximum operation pressure	0.5	[MPa]
Maximum pressure	1	[MPa]
Maximum temperature	45	[°C]
Maximum mass flow	2	[kg/s]

Table 2. The Main operating parameters of the Cooling water circuit

The oil cooler intermediate circuit consists of the oil pump OP, storage tank and oil cooler CH1 and CH3. The Oil cooler intermediate circuit is used due to the high temperature in the primary circuit behind the pressure reducer RV. As a cooling medium Marlotherm®SH oil is used. The main operating parameters of the Oil cooler are shown in Table 3.

Name	Value	unit
Maximum operation pressure	0.5	[MPa]
Maximum pressure	1	[MPa]
Outlet temperature CH1	250	[°C]
Outlet temperature CH3	100	[°C]
Maximum mass flow	0,4	[kg/s]

Table 3. The Main operating parameters of the Oil cooler

DESIGN OF THE LOOP

Key components of the loop are the heat-exchanger and Test Section. The heat exchanger is designed to be a modular allowing study heat transfer in various cycle compositions. Test Section is important part of the loop allowing the material research under S-CO2 conditions. It is possible to test and study small components such as turbine blades in it.

Design of Heat-exchangers

Heat-exchanger is designed as a counter-flow tube-type exchanger and it consists of eight pressure tubes. The outer diameter of the main pressure tube is 50 mm (1,968 in) and wall thickness 5 mm (0,197 in). This part of heat-exchanger is designed for limited pressure 15 MPa. Inner part of the heat-exchanger consists of seven tubes of diameter 10 mm (0,334 in) with wall thickness 1,5 mm (0,059 in). Inner tubes are designed for limited pressure 30 MPa.

Counter-flow parts are limited by temperature 450 °C. Total length of the heat transfer surface is 10 meters (32,81 ft), for one exchanger.

The cross section of the counter-flow heat-exchangers is shown in the figure 2.

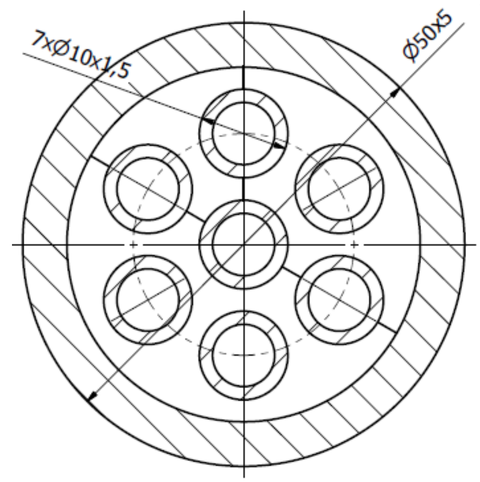

Figure 2. Cross-section of exchanger

Design of Test-Section

Test section consists of a removable tube of diameter 22x4 mm (0,866x0,157 in). For the specific experiments this tube could be replaced. According to the experiments (depends on the testing components) TS could be modify for different dimensions. It is also possible to incorporate additional devices, for example the mixer diaphragm, heater etc. due to the operating experiment.

Main goal of the fundamental experiments is to get values necessary for determining heat transfer coefficient α and the dynamic viscosity. When the friction coefficient λ and power of the heater are known it is possible to determine α, kinematic viscosity and thermal conductivity. These are achieved by calculation using criterion equations for the Reynolds number and the Nusselt numbers.

For measurements it is needed the uniform flow throughout the test section. The minimum length of the test section about 50 D_e (50 hydraulic diameters) is required. It is also necessary to keep the same length before and after the test section. The main reason is to ensure the same flow conditions before and after the test section are achieved. For experiments where the main goal is to determine the thermal conductivity, it is necessary to get uniform temperature field. For this reason the flow mixer has to be placed in the TS and the uniform temperature distribution along the channel could be achieved.

DISPOSITION OF THE EXPERIMENTAL LOOP

According to calculations of components of the loop were designed. The needed space for the loop is 2.5 x 3.7 x 3.7 m. The height of floors steel construction is 2.5 m (8,203 ft) and the length of the interior space for component's locations is 3.7 m (12,14 ft). The steel construction consists of two floors with a maximum height of 5 meters (16,41 ft). Above the steel construction there is a space for handling components, which are carried out by the traveling crane. Model of the experimental loop is shown in Fig.3

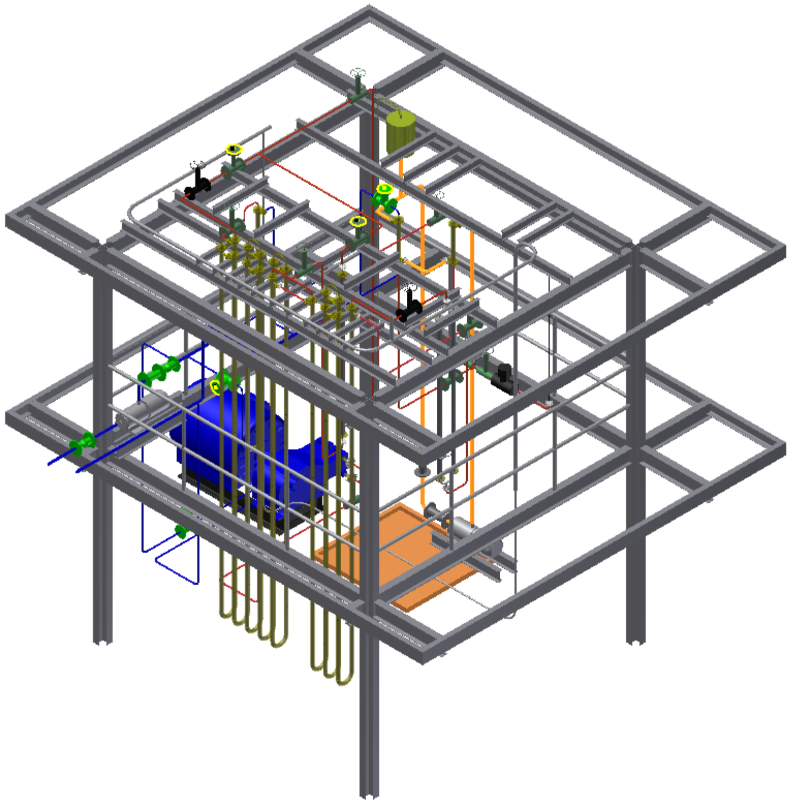

Figure 3. Model of experimental loop

The heaviest components are placed on the sides and the hottest components are placed in the middle of the dedicated space. For this reason, electrical heater is located in the middle area, LTR and HTR are located on the sides at the rear. The test section is located in the front for the easy access and manipulation.

CONCLUSION

Designed experimental S-CO_2 loop is currently the only project in Europe to create the conditions for experiments performed with S-CO_2. This loop can be precisely used for this uniqueness to attract the attention of the general scientific society across the Europe. Moreover, uniqueness of this experimental loop is the quite wide range and high level of the operating parameters (temperature and pressure).

The loop is designed to be widely adjusted according to customer requirements for the performed experiments. First tests of the experimental loop are paned for 2015, specific test then for 2016.

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