Supercritical Carbon Dioxide Based Heat Exchanger on the Martian Surface

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Abstract

The use of supercritical carbon dioxide (sCO2) in power cycles has been fairly new in the last decade. Due to this, there is a lack in research for both terrestrial and extra-terrestrial applications. The purpose of this project was to utilize sCO2 as a working fluid and design and optimize a Brayton Cycle based heat exchanger on the Martian surface. Carbon dioxide is already found on Mars limiting the need to transport a large amount of working fluid and helping with extra-terrestrial travel. Due to the lack of water on Mars, this research provides a stronger analysis of planetary based dry-cooling processes in low atmospheric pressure and colder temperatures. An in-depth analysis of the heat exchanger was conducted by modeling and validating the changing variables and parameters of sCO2. These include how the density, enthalpy, and kinematic viscosity of sCO2 change due to the pressure and temperature within the heat exchanger. Further research can include designing and conducting an analysis of the inside and outside geometries of the heat exchanger and which materials will be the most appropriate for transportation and efficiency.

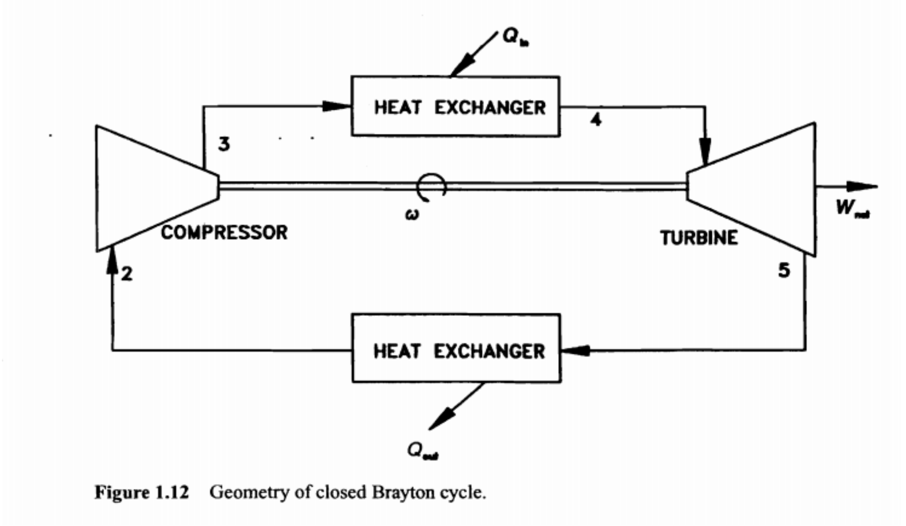

Figure 1

Variable Analysis

Since research of sCO2 as a working fluid is fairly new there are not known and published values of many properties. The values of density, enthalpy, and kinematic viscosity were needed for analysis. These values had to be obtained by developing equations based off of pressure and temperature. The properties from the gaseous region of carbon dioxide were used to develop the equations for density and enthalpy. The values of kinematic viscosity from the supercritical region of carbon dioxide were used to develop an equation for kinematic viscosity. Seen in Figure 2 are the values for enthalpy at the gaseous region as well as the linear trend line for each set of temperatures.

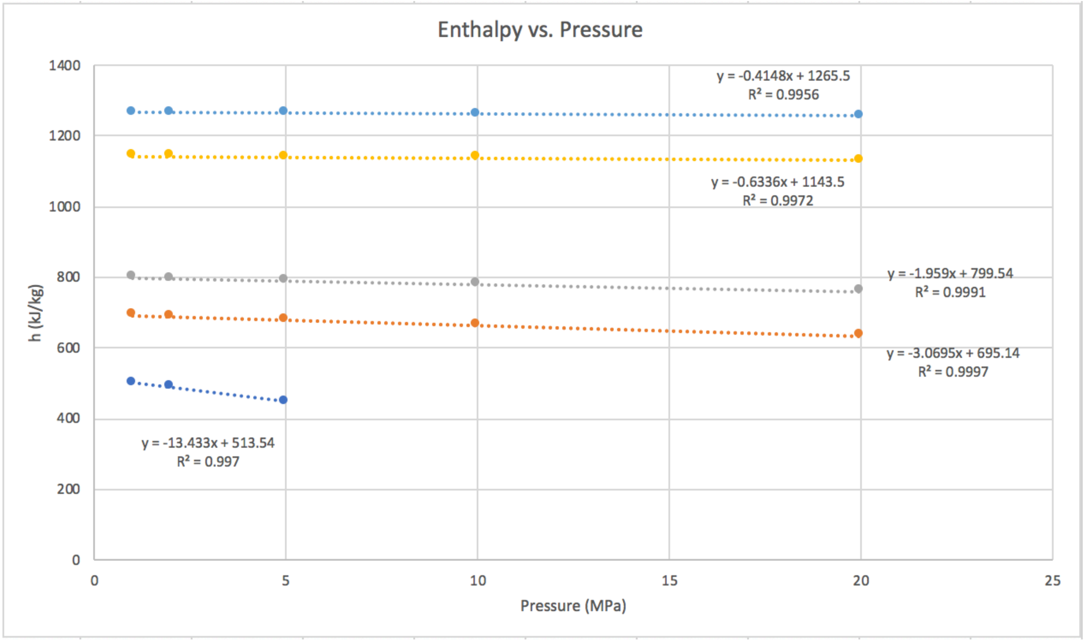

Figure 2

The trend is linear and there is an offset due to temperature. An equation based off of pressure and temperature was developed by using the trend of the data and optimized for the lowest average error. In this case the average error was 2.37%.This equation was then used to obtain enthalpy for carbon dioxide in the supercritical region. The process illustrated above was performed for both density and kinematic viscosity.

Heat Transfer Analysis

The heat exchanger was analyzed as a pipe horizontal to the Martian surface and sky. Due to the environment on Mars only radiation was accounted for and the convection was negligible. The conduction through the walls of the pipe was also neglected. The top half of the pipe exchanges heat with the sky while the bottom half exchanges with the ground. The parameters for this analysis were based on previous research. The parameters included the mass flow rate, initial and final temperature, and initial and final pressure of sCO2. The pipe was assumed to be commercial steel. Based off of this data a diameter was selected and the Reynolds number and friction factor were calculated. The total heat transfer out of the pipe was calculated and then used to evaluate the new temperature of the sCO2 at one meter increments. This was performed until the desired temperature of 305 K was achieved. The pressure at each increment was calculated to be used in the equations developed for density, enthalpy, and kinematic viscosity as well as other equations. It was also used to verify the pressure stayed high enough for operating conditions. The data was then optimized to limit the mass of the pipe. One way this was accomplished was by increasing the diameter so there was more surface area and less piping required. The final result was a diameter of 0.032 meters and pipe length of 327 meters as seen in Figure 3. Further analysis will be conducted to limit the mass and weight of the pipe in the future.

Lenth Down the Pipe (m)	Heat Rate to the Sky (kW)	Heat Rate to the Surface (kW)	Total Heat Rate (kW)	Temperature at the end of the Section (K)
1	0.671	0.664	1.335	687.90
2	0.637	0.630	1.267	679.38
3	0.606	0.599	1.205	671.29
4	0.578	0.571	1.148	663.59
5	0.551	0.545	1.096	656.25
321	0.024	0.017	0.041	306.73
322	0.024	0.017	0.041	306.48
323	0.024	0.017	0.041	306.23
324	0.024	0.017	0.041	305.98
325	0.024	0.017	0.041	305.73
326	0.024	0.017	0.041	305.48
327	0.024	0.017	0.040	305.23

Figure 3

Further Research

Further research can be conducted to optimize the design of the heat exchanger and make the analysis model more real world conditions. This includes altering the geometry of the heat exchanger including adding fins to the outside of the pipe. Analyzing different materials to use for transportation and efficiency. Considering environmental conditions including dust storms, altitude, time of day, etc. This research can also continue into an analysis of the different mechanisms of the Brayton cycle including the compressor or turbine.

References

Flack, R., Fundamentals of Jet Propulsion with Applications, Cambridge University Press, New York, NY, 2005.