Data Center Cooling

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Introduction

The objective of this project is to design a heat exchanger that uses phase change to maintain server temperatures in an operational range while using less water than current solutions. The design has two main components: the valve and the casing. A refrigerant, R-134a, will enter and pool at the bottom of the heat exchanger's casing through the valve. Heat produced by the servers will transfer to the fluid and provide the energy necessary to change the refrigerant's phase and take heat from the system as it leaves in vapor form. The valve will regulate the amount of fluid in the heat exchanger. In case of above average server operation, fluid will be replenished to prevent drying out. In cases of below average server operation, the valve will close and prevent the heat exchanger from flooding. Hand calculations and various models incorporating fluid mechanics, heat transfer, and stress analysis have been used to solve this problem.

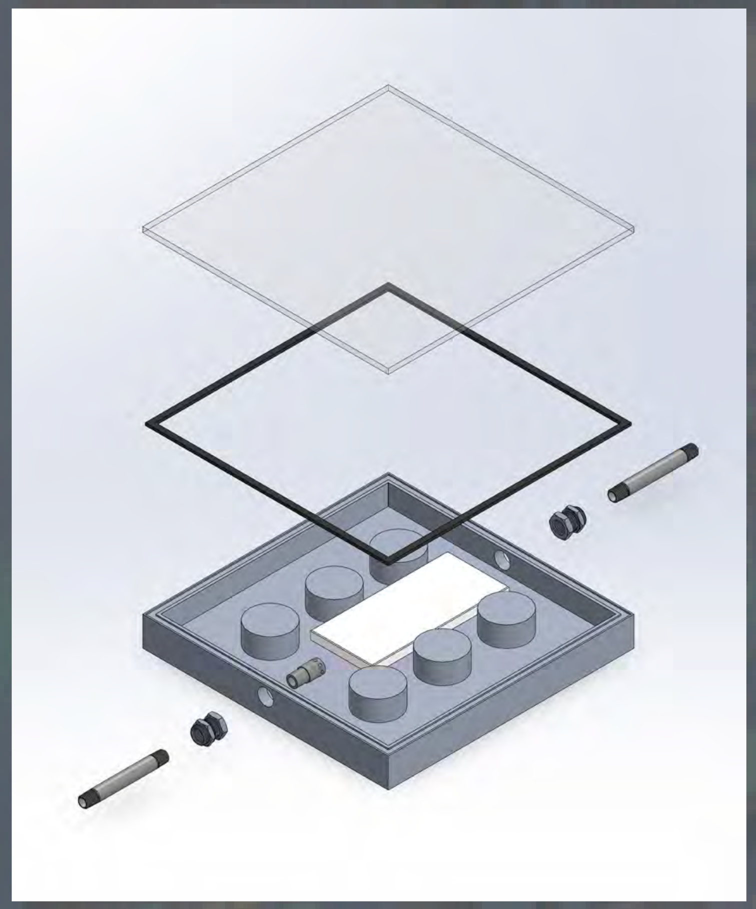

Figure 1: Case assembly exploded

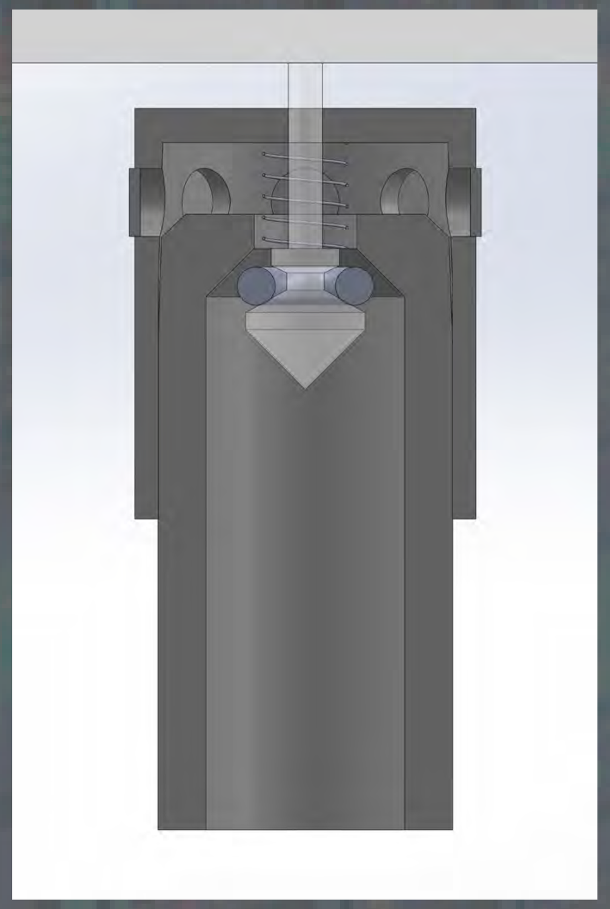

Figure 2: Valve internals

Problem

In the United State, data centers use between three and five million gallons of water per day and require over 100 megawatts of power. Around 43% of that power is dedicated solely to cooling systems. Reducing both the water and power consumption of data centers is critical to keeping up with public and private demand. This passively adjusting heat-exchanger does not rely on water and uses significantly less power than the standard Computer Room Air Conditioner (CRAC) and cooling towers in current use.

Methods

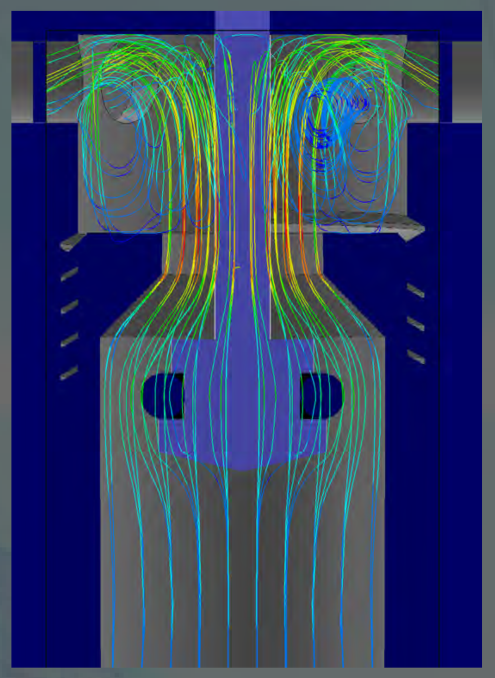

Figure 3: Flow trajectory plot of CFD simulation

CFD Simulations

Verifies that the inlet valve meets flow requirements necessary to prevent dry out and analyzes the forces on the stopper. The forces determined were used to design the float to help prevent valve-sticking.

FEA Analysis

Demonstrates the structural integrity of the case under maximum expected pressure to ensure safe operation.

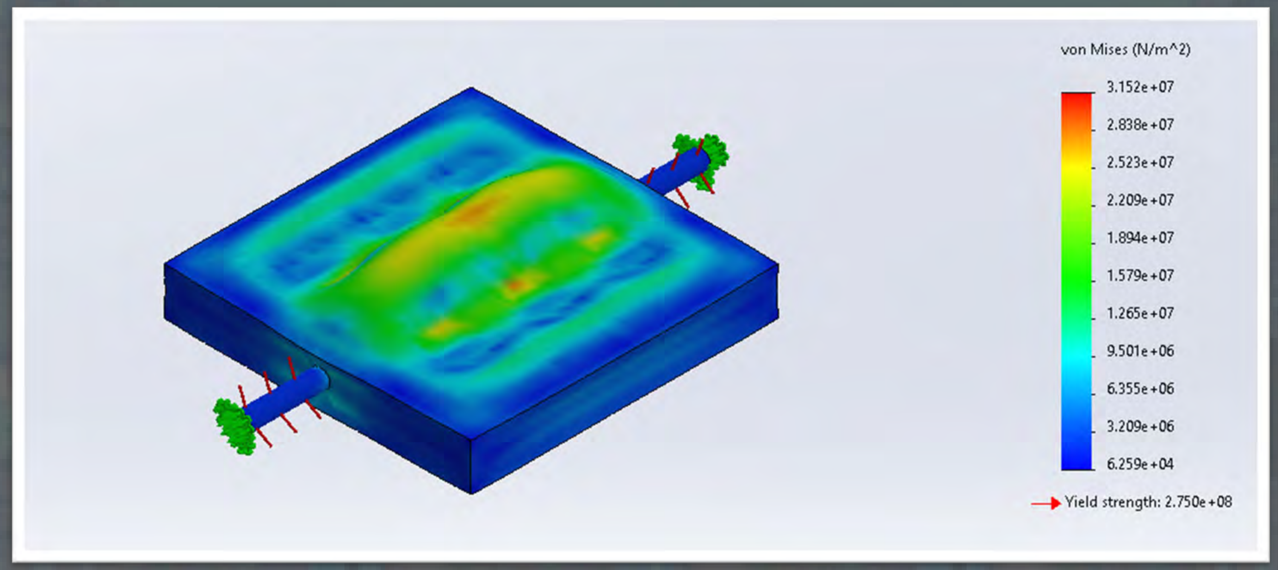

Figure 4: FEA analysis on heat exchanger case.

EES Model

Based on heat exchanger dimensions specified by the FEA analysis to prevent case deformation under high pressures, Engineering Equation Solver (EES) was used to determine the operating temperature and pressure needed to achieve a heat transfer rate that keeps the servers below the desired temperature.

Table 1. Operating pressure, saturation temperature, and heat transfer coefficient are shown with respect to server temperature with the assumption of removing at least 230 kW/m² from two servers, one mounted on each side of the heat exchanger

Server Temperature [C]	Operating Pressure [kPa]	Saturation Temperature [C]	Heat transfer coefficient [kW/m²-K]
50	864.5	26.8	31.8
45	748.6	21.4	30.5
40	643.7	16.0	29.2
35	550.7	10.52	27.9
30	468.2	5.058	26.8
25	395.4	-.4398	25.6

Results

The FEA analysis identified a maximum stress of 31.52 MPa under the highest possible operating pressure creating a 5.9 safety factor for the case material, aluminum 6061-T6, under tensile stress. The CFD simulations showed in a volumetric flow rate range of 80 and 160 cm³/s for a pressure difference across the valve between 20 and 120 kPa. This flow rate range confirms that the fluid will not dry out even under maximum operating conditions where the vapor exits the system at a rate of 11.7 cm³/s. The force on the stopper is at most 0.8 N over same pressure differential range, small enough to be overcome by the weight of the float and stopper to open the valve.

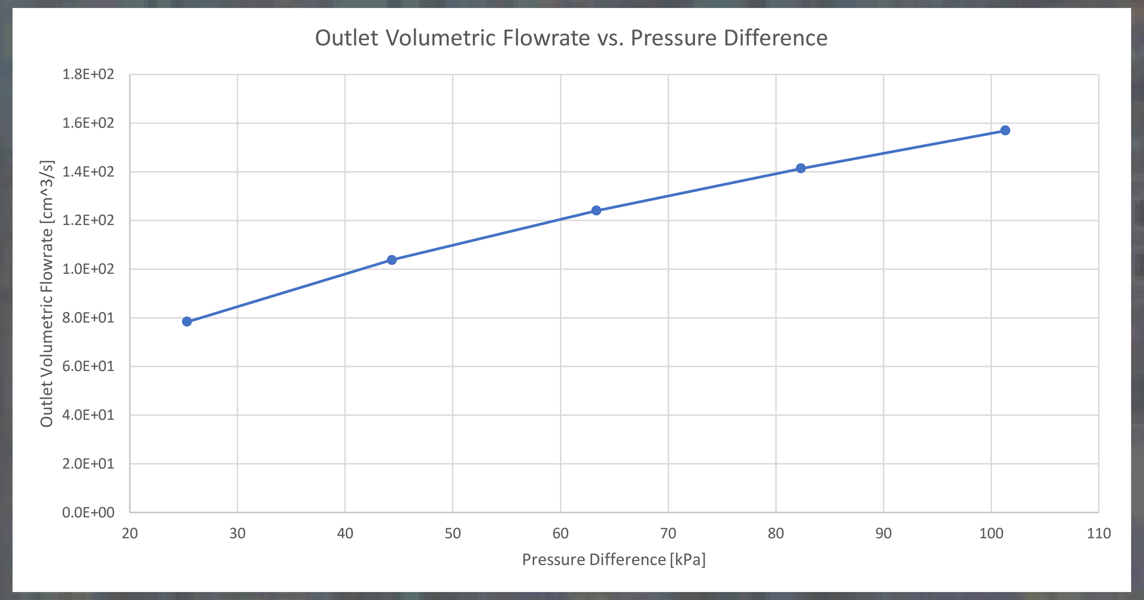

Figure 5: Plot of outlet volume flow rate vs. pressure difference in valve taken from CFD simulations.

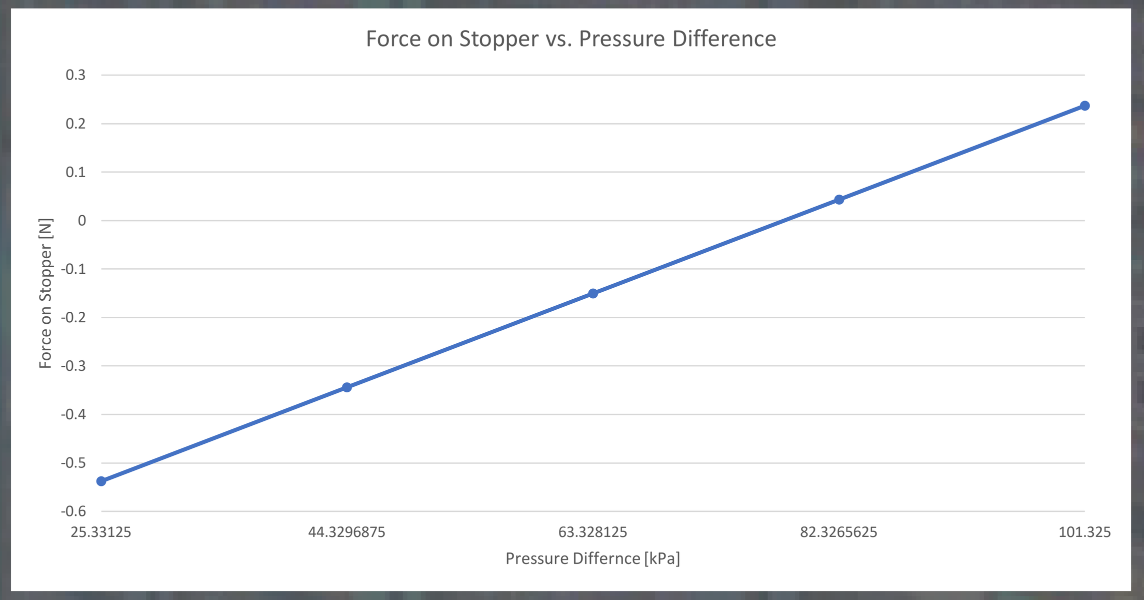

Figure 6: Plot of vertical force on stopper vs. pressure difference in valve taken from CFD simulations

Conclusion

Altogether, each of the models inform one another to show that the heat exchanger can operate safely, with proper valve operation, and dissipate the required amount of heat. Thus, we recommend this design as it can successfully cool data center servers in a manner that will drastically reduce water usage. However, it should be noted that due to the pressures required for operation, the device will be considered a pressure vessel in multiple states and must adhere to rigorous safety standards. One such standard would require a pressure relief valve at the exit which we recommend as well.