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Preliminary Simplified Calculations

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Project: Vortex Vacuum Chamber – Proof of Concept
Client: Infinidium Corp. (Att. Mr. Paul Gill)
Consultants: Dr. Arman Hemmati EIT

Initial Design Analysis

Preliminary analysis of the cooling system design reveals a number of misrepresentations that need to be addressed. Here is the more logical 2D visualization of the design as it stands:

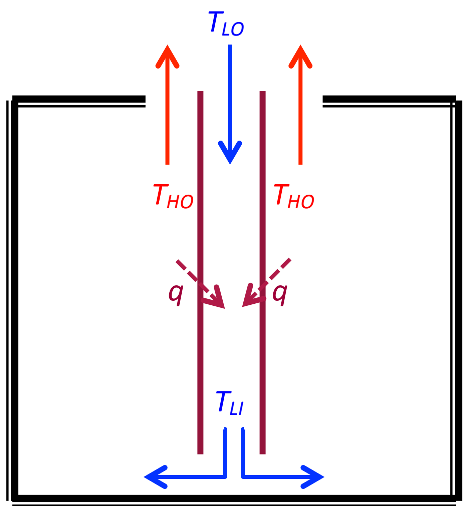

Figure 1: Original design of the Vortex Vacuum Chamber

Here, $T_{Lo} \neq T_{Li}$ since $q \neq 0$ inside the chamber causing heat transfer between hot and incoming cold air. Similarly, the mixing of the air at T_{Li} and T_{Ho} means that the exiting air mixes with cold air intake, which reduces the overall temperature gradient. It is also known that dT/dt is directly proportional to the flow velocity.

There are a number of design flaws that need to be addressed:

1- The cold air intake and the hot air outlet cannot be at the same location (vertical distance from the bottom of the chamber. The cold air intake must be placed higher than the hot air to allow for the flow of air through the intake with no interruption and/or thermal diffusion due to mixing.

2- The cold air channel at the center of the chamber will experience a large temperature gradient that will increase its temperature before it reaches the outlet at the bottom of the chamber. This can cause inefficient buoyant flow. The greater temperature gradient between injected air and omitted air (inside the chamber), the higher the flow rate and higher the efficiency of the system. This is especially important since the entire system relies on natural convection of air and no forced flow (fan). The recommendation is to make the cold air channel insulated to avoid temperature gradient between intake (top of the chamber) and outlet (bottom of the chamber).

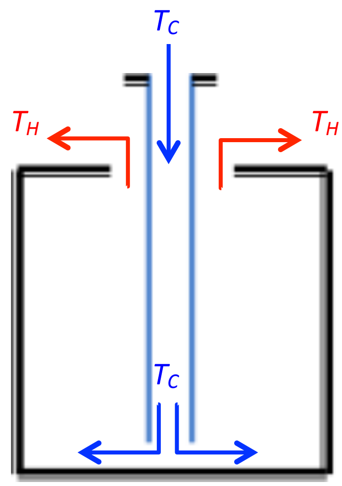

Figure 2: Modified cold air intake on the Vortex Vacuum Chamber with insulation.

3- Since the incoming cold air does not have a high velocity, the impinging flow at the bottom of the chamber will not be sufficient to facilitate the hot air outflow at a desire flow rate. There are a number of improvements that can be made to improve the performance of this system:

   a. Change the channel width as it moves down the chamber to increase velocity by reducing the cross-sectional area of the channel.

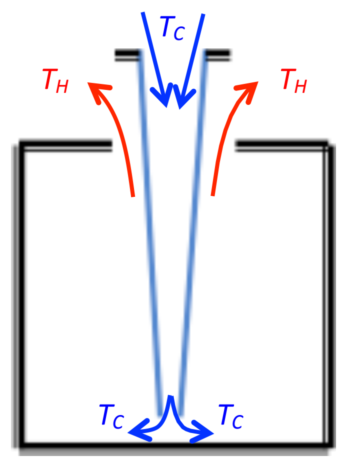

Figure 3: Modified air intake channel inside the Vortex Vacuum Chamber

   b. Place small nozzles at the bottom of the cold air channel facing the sides to further increase the velocity of incoming flow and result in a larger outflow rate. This mechanism will use the fundamental idea of conservation of mass to speed up the flow without the need to use a mechanical fan to induce external velocity in the system. Increasing the velocity will enhance convection and improve the cooling efficiency of the system.

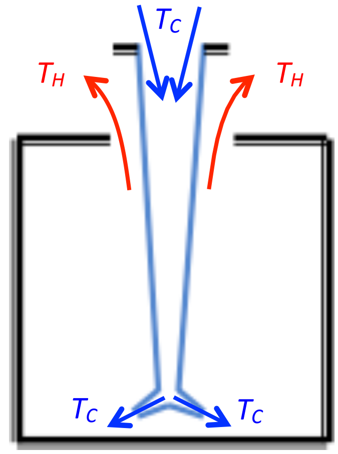

Figure 4: Addition of exit nozzles to the Vortex Vacuum Chamber

c. Place Venturi-shape around the chamber to enforce the flow in a rotational manner, similar to a vortex structure. A similar design improvement can also be made at the hot air outflow to facilitate exiting flow.

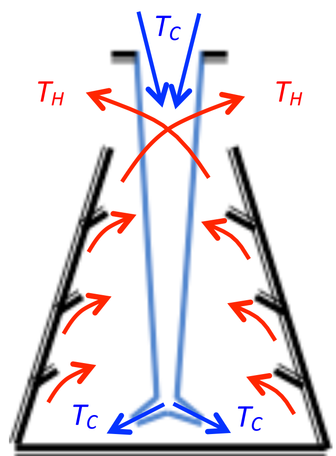

Figure 5: Venturi-Shaped chamber structure for Vortex Vacuum Chamber

The angle induced by the geometry will increase the velocity in the vertical direction, which is further assisted by the airfoil shape of the drive placed at the internal walls of the chamber. This setup will dictate the flow orientation and enhance efficiency of the system by increasing vertical airflow velocity and reducing cross flow velocity.

A simplified engineering analysis of the heat transfer is carried out to evaluate the performance of this system. The system is assumed to be a large channel with one wall kept at a constant temperature of 80-degree C, which is the ideal case for a running GPU according to your proposal for AI. The assumptions are:

- The radius of the chamber is sufficient so that $R >> \delta$, where δ is the boundary layer thickness and R is the chamber radius. This allows us to simplify the system as an external vertical wall that is kept at a constant temperature ($Tw = 80\ °C$).
- The bulk temperature is assumed to be the average of cold intake and the wall, that is $T_\infty = 53.5\ °C$.
- The dominating heat transfer is via natural convection since the velocity of intake air is relatively small compared to size of the system.
- Air properties can be assumed to remain constant since the temperature gradient is relatively small ($< 30°\ C$).
- The volumetric expansion rate (β) is estimated as ($1/T_f = 0.00294$ 1/K).

Using the *Nu* number, defined below based on the *Ra* number,

$$Nu = \left[0.825 + 0.387 \frac{Ra^{\frac{1}{6}}}{\left(1 + \left(\frac{0.492}{Pr}\right)^{\frac{9}{16}}\right)^{\frac{8}{27}}} \right]^2,$$

we obtain the problem heat transfer parameters:

$$r_0 = 0.998 \quad kg/m^3$$

$$C_p = 1.009 \quad kJ/kg\ K$$

$$v = 2.08\ 10^5\ m^2/s$$

$$k = 0.03003 \quad W/m\ C$$

$$Pr = 0.697$$

$$\alpha = 2.98\ x10^{-5} \quad \mathrm{m^2/s}$$

$$\beta = 0.002942 \quad 1/K.$$

The average convective heat transfer, therefore, is found to be $\underline{\boldsymbol{\bar{h} = 5.185\ W/(m^2K)}}$. Subsequently, the rate of heat transfer due to convection is calculated using the Newton Law of Cooling:

$$\dot{q} = \bar{h}\ A\ \delta T = 3.963\ kW$$

Therefore, each chamber can handle a heat transfer rate of up to **<u>3.963±1.000 kW</u>** based on the aforementioned assumptions. Please note that this value is obtained based on simplifications that are outlined previously.