Term Project Report on

MASS TRANSFER ANALYSIS OF AIR PURIFIERS AND ITS DESIGN

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At

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Abstract:

The project tackles the sensitive issue of air pollution and its adverse effects on the people surrounded by it. Air purification is critical in recent circumstances with pandemics like Covid 19 hitting an entire population of billions of people. Without any acknowledgement to the issue in an ongoing industrial age like ours, the air pollution tends to increase in almost every city of the country. For instance, the environmental condition in Delhi NCR, with an air index of over 400, is an adverse effect of high levels of air pollution in the surrounding air which tends to extend to 98% of low-income towns with a population of over 1,00,000 people, which fail to meet WHO guidelines for healthy air quality (as per which, annual average concentrations of $PM_{2.5}$ should not exceed 10 $\mu g/m^3$). In a more concentrated sense, air purification is vital in hospitals, especially surgical wards where surgeons operate in the air medium. The air is often contaminated with microorganisms and pathogens leaving the human bodies most vulnerable to infections. Henceforth, the need to engineer air purification devices which can remove pollutants, as well as kill microorganisms arise. In today's time, air purifiers are as much a necessity as a water purifier.

The project presents the designs of air purifying devices and their simulations.

Background/Literature Review:

- Researchers have conducted extensive research on air filters and purifiers. Air purification technology is currently classified into two categories: capture and reactive. By filtration or adsorption, the capture type removes the impurities from the air-fluid, leaving the contaminants in the air purifier. By chemical reaction or ionization, the reaction type principle primarily removes gaseous pollutants (molecular type pollutants) from the air. However, this type of purification is prone to secondary contamination. Mechanical filtration, electrostatic precipitator (ESP), and hybrid air purifiers are the three most prevalent capture air cleaning technologies (Chan et al., 2015).
- The Hammer brothers from Germany invented the first indoor mechanical filter to remove soot from indoor air in 1963. During the Manhattan Project, USA in the 1940s, the United States produced the first HEPA filter, which was used to prevent the spread of radioactive contaminants in the air. Glass fiber or quartz fiber are the major components of HEPA. Good HEPA material may eliminate particle contaminants from the air with a 99.97 percent effectiveness. The essential attribute of this material is its great

particle collecting efficiency, but it also has a strong resistance. Long-term use of this filter may allow contaminants to escape, resulting in contaminants that are detectable by humans. As a result, mechanical air purifiers have a smaller market share.

  - Unlike mechanical air purifiers, the filter material in an electrostatic air purifier does not need to be replaced on a regular basis. The filter can be removed and cleaned for recycling once the power has been turned off. The electrostatic precipitator air purifier is more cost-effective and environmentally beneficial than a mechanical filter. However, because high-voltage electricity ionizes oxygen in the air, the electrostatic precipitator air purifier generates secondary pollutants, such as ozone, during operation, which is also the most significant disadvantage of this type of air purifier.
  - The main mechanism of action of adsorption air purifiers is physical and chemical adsorption. Physical adsorption frequently necessitates porous adsorbent support with a substantial specific surface area. To achieve the effect of eliminating pollutants, the intermolecular force is used to adsorb the pollutants on the adsorption carrier. Adsorption technologies are commonly used in today's standard air purifiers to remove dangerous gases or volatile organic compounds from the air, such as sulfur dioxide, nitrogen oxides, hydrogen sulfide, and others.

Numerical Simulation:

- **Introduction/Research Design:**
  - We have used ANSYS R21b for numerical simulations.
- **Analysis/Limitations:**
  - The time taken for simulation was considerably low as the larger time requires more iterations leading to a very slow calculation for hours.
  - The methods employed are less computation-intensive, leading to increased order of error.
  - The adsorptive power of the wall is considerably large, relatively, to observe significant changes.
  - Most of the conditions are taken in ideal cases, ignoring the external factors leading to slight errors.

- Design B is made in 2D to study the flow and adsorption mechanism with less computation in place of 3D simulation.

- **Separation process:**

  Unit Operations: -

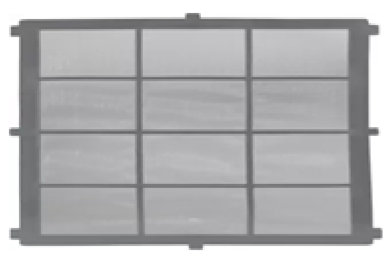
  1) Filtration

  2) Adsorption

  - Three different filters are used for the three stages of purification and sterilization of Air.

    This process consists of the following stages: -

    1) Pre-filter: - Removes larger dust particulates and irritants bigger than 50 microns.



    2) Hepa Filter: - Hepa stands for high-efficiency particulate Air. This filter can filter 99.97% of microorganisms and pollutants of size as small as 0.3 microns.

3) Carbon Filter: - It uses adsorption to filter Toxic gases, foul smells from the Air. It neutralizes most gases and Volatile Organic compounds.

Working of a HEPA filter: -

- HEPA filters are composed of a mat of randomly arranged fibres. The fibres are typically composed of polypropylene or fibreglass with diameters between 0.5 to 2 micrometres. These fibres create a narrow-convoluted pathway through which air passes.
- Particles below 0.3 µm are captured by Diffusion in the HEPA filter.
- Mid-size particles are captured by Interception. Particles following the flowline in the Air stream come within one of a fibre and adhere to it.
- Larger particles are unable to avoid fibres by following the curving contours of the air stream and are forced to embed in one of them directly; This effect increases with diminishing fibre separation and higher air velocity. This process is called Impaction.

Working of a Carbon Filter: -

- In Carbon filters, the pollutants present in the fluid get trapped inside the pore structure of the carbon substrate.
- This substrate is made of many carbon granules, each having high porosity resulting in a larger surface area to trap the contaminants.
- Generally, Activated Carbon is used in filters. This is because Activated Carbon is treated to have a much higher surface area than non-treated carbon. 1 gram of activated carbon has a surface area of more than 3,000 m^2 (32,000 sq. ft)

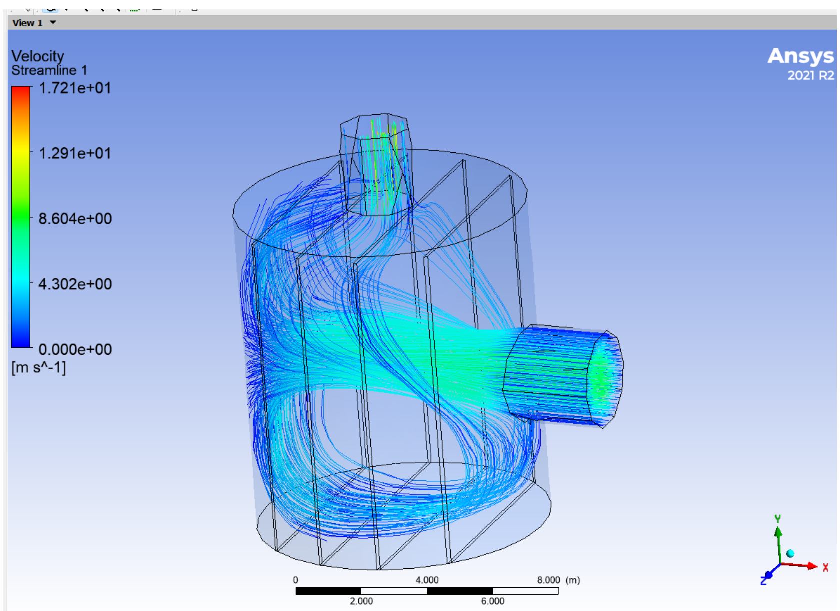
For simplification purposes, we have taken Air to be N_2 and a 2D geometry for faster calculations.

The Process is carried out at room temperature (25° C) and a Pressure of 1 atm.

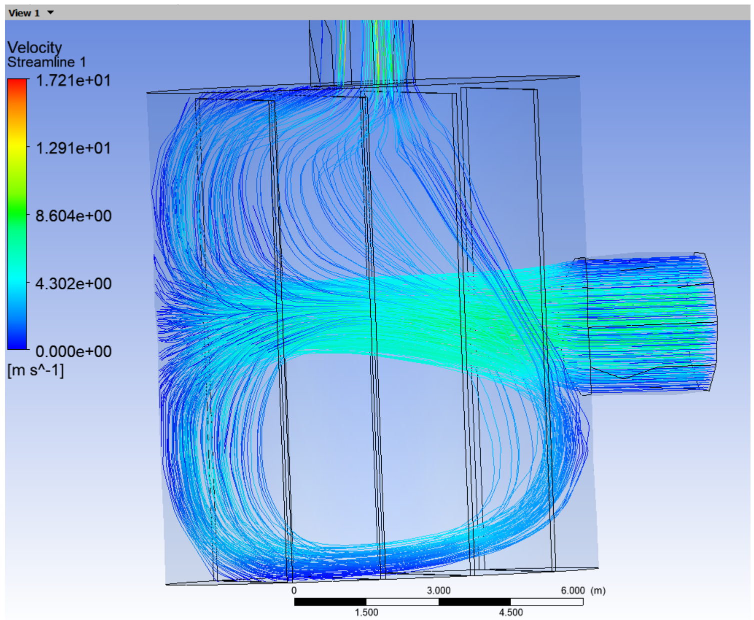
Feed Rate: - 1 kg/s

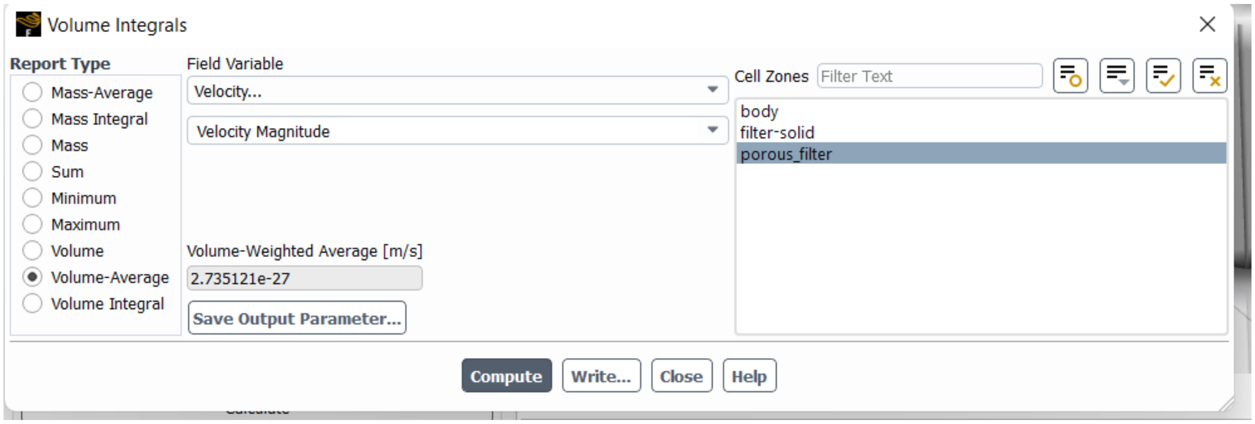
Design A:

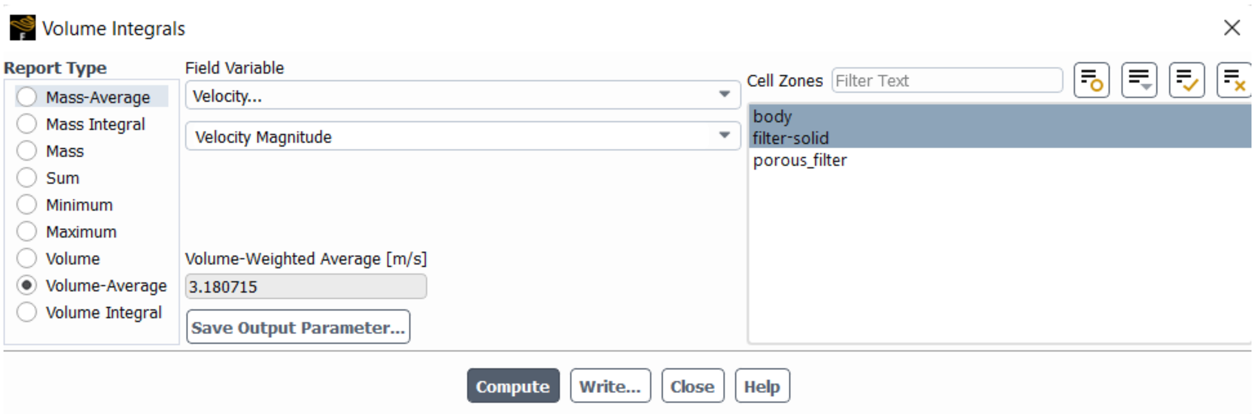
Velocity of air at inlet = 8m/s
Porosity = 0.1818
Here, we have added 4 porous medium of porosity 0.1818 to simulate as the filters



Showing deflections of few streamlines through porous media.



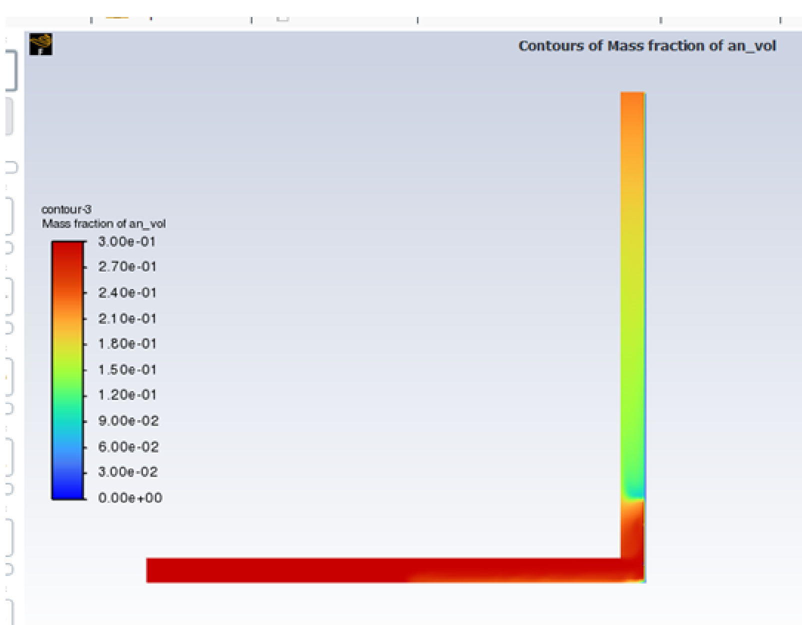




Volume weighted average of porous filter is far less comparative to body and filter-solid acting as fluid medium.

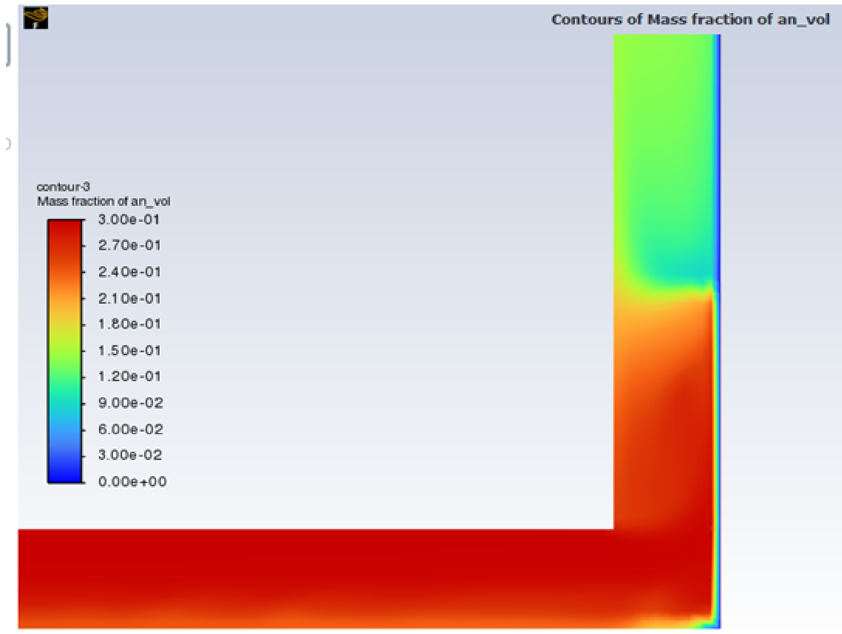
Design B:

Mass fraction of Anthracite_volatile(VOC) Contour plot:



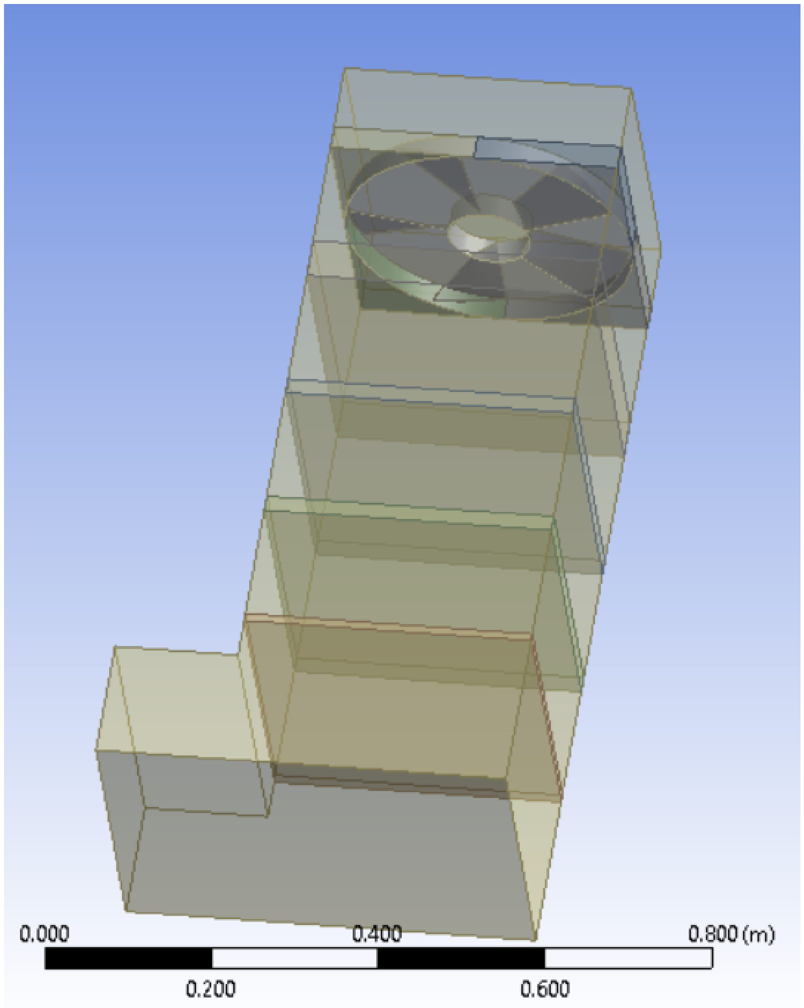
Mass fraction of Anthracite_volatile(VOC) Contour plot:

Zoomed plot



Design C:

Here, There are 2 pre-filters, 1 Carbon activated filter, 1 Hepa-filter, followed by a suction fan and then a chamber for UV lamps for disinfection .
I.e. filtration as unit operation and UV disinfection as unit process.
This is a proposed model made in Autodesk Inventor.
Here, Fan mesh would be rotating, filters would act as porous media and inlet would have anthracite solid particulate matter as discrete phase model to perform the simulation.



- **Calculations:**
  - **For Design B:**
    - Total area = 461.49m^2
    - Area of inlet = Area of Outlet = 0.5m^2
    - Mass weighted avg of anthracite at inlet = 0.3
    - Mass weighted avg of nitrogen at inlet = 0.7
    - Mass weighted avg of anthracite at outlet = 0.226
    - Mass weighted avg of anthracite at outlet = 0.773
    - Difference or mass fraction being adsorbed = 0.074
    - Area of adsorbent wall / Area of contact= 10m^2
    - Total area of mass of anthracite (in 2D geometry)= 0.3 * 461.49 = 138.45m^2 (0.3 mass fraction was initialized for VOC)

        - Area of mass of anthracite that got adsorbed = 0.4 * (10) (as 0.4 of the fraction gets subtracted from the original term and also 0.3 term is not multiplied as all the anthracite gets deposited near the wall)
        - Now 4/138 is about 0.028 which gets replaced by new fluid every second and hence comes out to be 0.074 at the end of simulation after 100s which is reasonably correct.

Conclusion :

- **Summary of findings:**
    - The amount of Anthracite volatile compound (VOC) mass fraction at walls is less than inlet mass fraction
    - The amount of Nitrogen gas mass fraction at walls is more than inlet mass fraction.
    - The amount of adsorbed volume of VOC increases over time as velocity of inlet is not very high and the fluid remains in the tube for longer duration and thus contact time from adsorbent wall increases.
- **Conclusions:**
    - From the findings, we can conclude that (for Design B):
        - The amount of fraction adsorbed VOC over the wall for the designed model comes out to be 0.074.

Future Scope and Challenges :

Ozone is produced by some air purifiers known as ionizers. Ionization is a feature that certain air purifiers have. This can help with particle clearance, but ozone is actively harmful to your health. Ionized particles adhere to surfaces more readily, such as the air filter. It does, however, adhere more readily to your lungs. As a result, it must be avoided. As a result, the US Environmental Protection Agency (EPA) advises against using ionisers.

Although the operating costs are low, the initial purchase might be difficult. Especially if you're looking for an excellent model.

Currently, most Air Purification technology uses HEPA & Carbon Filters which can provide solutions up to some extent. In a range of healthcare institutions and life sciences applications, HEPA filters have been shown to reduce the transmission of airborne particles and organisms such as viruses and bacteria. VironAire also introduced two cheap HEPA-based medical-grade air cleaners for hospitals, companies, and households in July 2020, during the COVID-19 epidemic. For viral killing, the systems use HEPA-13 and UV-C radiation with a wavelength of 254 nanometers. As a result of the aforementioned factors, the high-efficiency particulate air (HEPA) technology is likely to dominate the market in the future. In line with the Make in India philosophy, Air OK is the first indigenous air purifier firm with its own R&D and manufacturing in India. Air OK will soon provide corona disinfecting air purifiers to combat COVID-19, given the present major impact in the aftermath of the epidemic. In January 2020, AIIMS and IIT in India released the Airlines Car Air Sanitizer, a car air purifier capable of cleaning the air inside a vehicle in two minutes. The device complies with WHO regulations and employs Active Molecular Technology, which the inventors say is the world's first technology that operates without the use of an external energy source and preserves vehicle batteries.

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