1. (10 pts) As you know, coronavirus has been a serious pandemic in the world during the winter of 2020. We have seen pictures in the news of people wearing masks to protect themselves. Do some Internet searching and answer these questions: Are masks effective for protecting people from getting the coronavirus? Why or why not? Are masks effective for keeping people who have the coronavirus from spreading it to others? Why or why not? [As always with this kind of question, show your references and always be on the lookout for evidences of bias in the articles.]

2. (20 pts) In Homework 6, Problem 4, we plotted the hazardous zone downwind of an explosion of a nasty chemical. In that problem the explosion was at ground level ($H = 0$). Repeat if the tank were sitting at 1.5 m above the ground when it exploded ($H = 1.5$ m). Our goal is to see if the hazardous zone would increase or decrease in size (area) as compared to the case where the same gas is released at ground level. Note that we are still considering concentrations on the ground, not taking into account how tall people are.

   (a) Create a plot of the hazardous zone if everything is the same as the previous problem except $H = 1.5$ m. Plot both areas (last week, $H = 0$, and this week, $H = 1.5$ m) on the same plot and compare.

   (b) Discuss. Explain your results.

3. (20 pts) A horizontal elutriator is a simple device that is sometimes used at the inlet to an APCS to remove some of the larger diameter particles from the air. It consists of parallel horizontal plates, as sketched. Dirty air enters from the left at low air speed. As the air moves along, particles fall and settle on the plates. We assume that when particles hit the plate, they stick there and remain on the plate – they are removed from the air. After some time, the device may get clogged, so it needs to be washed out. However, there are no moving parts, it does not require electricity, and it is simple and effective at removing particles from the air. Heavier and/or larger particles settle quickly, while lighter and/or smaller particles take longer to settle. Therefore we expect the removal efficiency of the device to depend on particle diameter and particle density. For simplicity, consider SATP conditions with the incoming dirty air consisting of a well-mixed polydisperse aerosol of spherical particles of density $\rho_p = 1850$ kg/m$^3$ with diameters ranging from 0.1 to 10 microns. Air flows at an average speed of $U = 0.185$ m/s through the channels, the flow is laminar in the channels, the length of the horizontal elutriator is 0.400 m and the height between plates is $H = 1.25$ mm. For best accuracy in your calculations, include the Cunningham correction factor and the appropriate equation for drag coefficient (iteration is required).

   (a) Calculate the critical diameter, defined as the minimum particle diameter at which we predict 100% removal through the elutriator. In other words, particles greater in size than this critical diameter will all settle out and be removed, whereas particles smaller than this critical diameter will be only partially removed (efficiency less than 100%). You may have to do some iteration. Your answer should lie between 3 and 5 microns if you do the calculations correctly.

   (b) Generate a plot of grade efficiency $\eta(D_p)$, defined as the removal efficiency of aerosol particles as a function of particle diameter. Note that each particle diameter generates a different grade efficiency since larger particles fall faster than smaller particles. In your calculations, if $\eta > 100\%$, set $\eta = 100\%$ since it is impossible to have a removal efficiency greater than 100%. For consistency, draw your plot with a horizontal log axis for $D_p$ and a vertical linear axis for $\eta$ from 0 to 100%. Use enough data points to make a nice-looking grade efficiency curve. What is the “cut diameter” (the particle diameter at which the removal efficiency is 50%) for this device?

   (c) Briefly comment about this device – when might it be useful, and what are its limitations?

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**Note:** There is another page. →
4. (20 pts) In class we discussed several equations and approximations for calculating the terminal settling velocity $V_t$ of particles in quiescent air. Consider unit density particles settling in quiescent air at SATP conditions. On the same plot, draw three curves of $V_t$ vs. $D_p$:

- **Best estimate**: Use appropriate equation for $C_D$, depending on Reynolds number; apply Cunningham correction factor, and iterate as necessary to obtain the best possible estimate of drag coefficient and terminal settling velocity.
- **Stokes approximation with Cunningham correction**: Use $C_D = 24/Re$ regardless of the value of $Re$; apply Cunningham correction factor and iterate as necessary to obtain the Stokes flow estimate of terminal settling velocity.
- **Best estimate of $C_D$, but no Cunningham correction**: Use appropriate equation for $C_D$, depending on Reynolds number; ignore the Cunningham correction factor (set $C = 1$), and iterate as necessary to obtain the best estimate of terminal settling velocity when $C$ is ignored.

For consistency, make your plot a log-log plot, with $D_p$ ranging from $10^{-3}$ to $10^4$ microns on the horizontal axis, and $V_t$ ranging from $10^{-8}$ to $10^2$ m/s on the vertical axis. For full credit, print out your plot, and make sure the axes and data sets are clearly labeled with a legend or other label. Finally, summarize and comment: Specifically, for what range of particle diameter is it okay to ignore the Cunningham correction factor? For what range of particle diameter is it okay to use the Stokes approximation?

5. (30 pts) Consider air pollution from a hot plume emitted by a stack of height 90 m. The additional plume rise height due to buoyancy is 40 m. The air pollutant reflects from the ground (is not absorbed). The atmosphere is Class C from the ground to 150 m, at which point there is an elevated temperature inversion (from 150 m to 450 m). The wind speed is 3.5 m/s, and the pollutant is emitted at a steady rate of 3.8 g/s. In your calculations, consider only the centerline directly downwind of the plume ($y = 0$). Also, consider only ground-level exposure ($z = 0$).

There are two ways or methods to solve this problem:

- **(A)** Using the equation we generated in class that models the plume as a source plus an infinite number of image sources (to account for both the reflecting ground and the reflecting inversion).
- **(B)** Using the fumigating plume approximation, in which we approximate the plume concentration as well mixed vertically at any $x$ location downwind (also discussed in class).

Note that the equation for method (B) is on the Equation Sheet, but the equation for method (A) is not. It was given in Lecture 18 and is repeated here for your convenience.

\[
c_j = \frac{\dot{m}_{j,x}}{2\pi U\sigma_y\sigma_z} \exp \left[ -\frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 \right] \sum_{j=-\infty}^{\infty} \left[ \exp \left[ -\frac{1}{2} \left( \frac{z-H-2jH_T}{\sigma_z} \right)^2 \right] + \exp \left[ -\frac{1}{2} \left( \frac{z+H-2jH_T}{\sigma_z} \right)^2 \right] \right]
\]

**(a)** Consider the simpler case first – method (B). At $x = 3.5$ km, calculate the well-mixed fumigated mass concentration $c_{j,F}$ of the contaminant in units of $\mu g/m^3$. Recall that a given downstream location, this value is approximated as constant from the ground to the bottom of the temperature inversion, since we are assuming well-mixed conditions vertically. Plot $c_j$ as a function of $z$ from the ground to the bottom of the temperature inversion. For consistency, make $c_j$ the horizontal axis and make $z$ the vertical axis on your plot (your result should be a straight vertical line).

**(b)** Now repeat using method (A). Obviously, you cannot calculate an infinite number of image sources. Instead, do two cases: one including all the image sources for $j = -1$, 0, and 1, and another including all the image sources for $j = -2$, -1, 0, 1, and 2. Plot these results on the same plot as that of Part (a). Make sure you label each case.

**(c)** Compare and discuss. Are the results as expected? How good is the well-mixed approximation? What do you think would happen if you repeat the calculations including even more image sources? What do you think will happen if you were to repeat at an $x$ location much farther downwind? Would you need to include more image sources?