Project 2 Report: Analyzing the Effectiveness of a Smog Free Tower

Team 11

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Mr Owin Fung, JP,

We are writing to inform you of our findings for the best possible implementation of the Smog Free tower for cleaning the polluted air in Hong Kong. Our team went through an extensive research and design process to craft a computational model that takes into account the many different forces that would act on the pollutants to simulate how effective the Smog Free Towers could be.

This model we have created has been used extensively to determine the efficacy of the towers if deployed. We also did substantial research on the air quality throughout Hong Kong and in conjunction with our model, determined the best places to deploy these Smog Free Towers. In our initial findings, we have determined that the Smog Free Towers could be effective when deployed as recommended. We also analyzed some of the potential issues that may come up when scaling up this project to a full city-wide deployment. Our further findings will be detailed in our full report.

We wish you the best as you and your team move forward with the possible deployment of these Smog Free Towers, and we will be available to answer any further questions as needed to aid in the understanding of the results we have provided for this feasibility study.

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Executive Summary

The problem that the team aims to solve is to determine the best possible implementation of the technology in the "Smog Free Tower" to be deployed in Hong Kong. The team was tasked with creating a computer model to simulate the effects of the Smog Free Tower on the pollutant particles to determine how effective the towers would be on the surrounding environment.

The model the team created takes into consideration the charge of the sheet, the charge of other charged particles, the buoyancy, and the force of gravity. The team believes this model creates an accurate representation of the effect the tower has on the surrounding area.

The team then used the model created to run many simulations to determine exactly how effective the Smog Free Tower would be. The team determined that the best implementation of the towers would be to place 1000 towers around Hong Kong with the most pollutants. The team did a detailed analysis of the most polluted areas of Hong Kong that would be the best for deployment. This is detailed later in our report. The team determined that this deployment would be within the Environmental Protection Department of Hong Kong's budget for cleaning up air pollution of $2.4 Billion. This deployment would be able to remove all the current pollutants in Hong Kong in 3.4 years.

This estimate, however, does not take into account all of the pollutants that will be emitted past the date that the towers are deployed. If the towers are deployed for the 3 to 4 year period as recommended, the towers would need to be made out of material that is not only sustainable, but is also strong enough to withstand strong winds, rain, monsoons, and other weather events over the given period of time.

Overall, the team fully believes that if the Smog Free Towers are deployed as recommended, they will have a significant impact on the air quality of Hong Kong.

Analysis of Technology

To begin the discussion of the implementation of the Smog Free Tower (SFT), the team had to assess the effectiveness of an electrostatic precipitator at removing specific pollutants (e.g., NO_2, SO_2, $PM_{2.5}$, PM_{10}, etc.) from the air. The objective of this investigation was to come to a conclusion on the validity of the technology, and if the technology is valid, how much air a single SFT is capable of cleaning in a given amount of time. With those objectives in mind, the team decided the best approach to assess the validity of the tower was to create a physics simulation of how a single particle would behave when in proximity to the SFT in MATLAB.

To begin the creation of the model, the team came up with a list of assumptions that would allow for quick development while still producing results that would allow for an accurate conclusion to be drawn about the technology of the SFT. The model operated off of 4 fundamental assumptions, listed below.

The electric plate in the SFT is infinitely large compared to a pollutant particle:

This assumption allowed the team to simplify the calculations involving the electric field produced by the electric plate in the SFT, as the team was able to ignore the effect of the edge of the electric plate on the pollutant particles.

The effects of wind are ignored:

This assumption allowed the team to complete the model by the deadline requested by Mr. Fung, as the calculation of wind is an extremely involved process the team was not equipped to handle during the time of the analysis.

Stoke's Flow:

The assumption of Stokes flow greatly simplifies the calculation of drag in the model, effectively making it possible for the team to include drag in the model with their limited knowledge of fluid dynamics.

Negligible Lift, Intermolecular Forces:

In preliminary calculations, the team determined that lift and IMFs would result in less than one percent of total force when added to other relevant forces in the model. By assuming negligible lift and IMFs, the team was able to remove the equations for these forces from the MATLAB model, simplifying the final equation.

With the fundamental assumptions in place, the team began developing the physics simulation, containing buoyancy, drag, electric plate force, and force due to other charged particles, using a tower of size 2m x 2m x 10m. Fundamental constants were added to the MATLAB model to prepare for the addition of force equations, including factors such as air density, gravity, coulomb's constant, etc.. In order to make the model comprehensive, the team decided on the inclusion of several types of pollutants, including NO_2, SO_2, NO, CO, C_6H_6, PM2.5, and PM10, as they were the most frequently listed pollutants in our research of the Hong Kong area. The inclusion of different pollutants was important, as each particle has different charge, diameter, and density that leads to different interactions with the SFT.

```
% Data for types of particles (Iteration Variable)
% 1: NO2 (Nitrogen Dioxide)
% 2: SO2 (Sulfur Dioxide)
% 3: NO (Nitric Oxide)
% 4: CO (Carbon Monoxide)
% 5: C6H6 (Benzene)
% 6: PM-2.5 (Soot)
% 7: PM-10 (Soot)
```

Figure 1. List of pollutants included in model

```
%% Particle Measurments

diameter = [3.94e-10, 4.4e-10, 2.62e-10, 2.7e-10, 6.76e-10, 2.5e-6, 1e-7]; % Particle Diameter
p_particle = [3.663, 2.629, 1.3402, 1.14, 3.486, 1780, 1780]; % Particle Density
charge = [c_electron, 0, -2 * c_electron, 0, 0, c_electron, -c_electron]; % Particle Charge
```

Figure 2. Physical properties of pollutants

The use of arrays to include the physical properties of several different pollutants increased the robustness of the model, as the simple change of an iteration variable changes all of the physical properties of the particle at once, increasing ease of use to see how different pollutants behave. After the implementation of constants and physical properties, the forces necessary were implemented in the physics model.

Sheet Charge:

$$F_{Sheet} = -\frac{q\sigma}{2\pi\varepsilon_0}$$

Only one factor in the sheet of charge equation was decided by the team, which was charge density σ, with the other factors in the force being determined either by physical properties of the particle (q) or fundamental constants. The team decided on a charge density of 150 C/m^3 after trial and error in the physics model.

Drag:

$$F_{Drag} = \frac{1}{2}\rho_{air}C_d * (\frac{\pi}{4}\ d^2_{particle}\ \ ) * v^2_{vert}(t)$$

There were no factors in the equation for drag that had to be chosen by the team, but drag remained one of the most important forces in the model due to it being the determinant of the terminal velocity of the particle.

Gravity:

$$F_{Gravity} = \frac{\pi}{6}(\rho_{air} - \rho_{particle})gd^3_{particle}$$

The addition of buoyancy to the gravity equation allows for a higher level of accuracy without making the equation too complicated to work with.

Other Charged Particles:

$$F_{Charged\ Particles} = \frac{q^2c(t)}{2\varepsilon_0} * [2D_{vert}(t) - H]$$

An important factor to note about the force due to charged particles is the concentration of the particles over time as the particle moves closer to the tower. The team came to the conclusion that the concentration would decrease linearly as the particle moved towards the electric plate, as the air in theory should contain fewer pollutants as it has been “cleaned”. The other factor that was decided by the team was H, the height of our tower, which was 10 meters in our model. The rest of the force is defined by fundamental constants or the differential equation discussed later in this section.

The above forces were combined into a differential equation based on Newton's second law, F = ma, and then split into 2 first order differential equations via a user defined function that prepared our equation for integration. The findings for a PM2.5 particle can be seen below.

```
function dydt = ode_func(t,y, timestep, f_sheet, f_drag, f_charged, f_g, divisor, h)

y1 = y(1);
y2 = y(2);
dy1dt = y1 + y2 * (timestep);
dy2dt = y2 - ((-f_sheet + (f_drag * y2) + f_charged  * ((2 * y1) - h) + f_g) / divisor) * timestep;
dydt = [dy1dt;dy2dt];
end
```

Figure 3. User defined function to convert differential equation into two equations

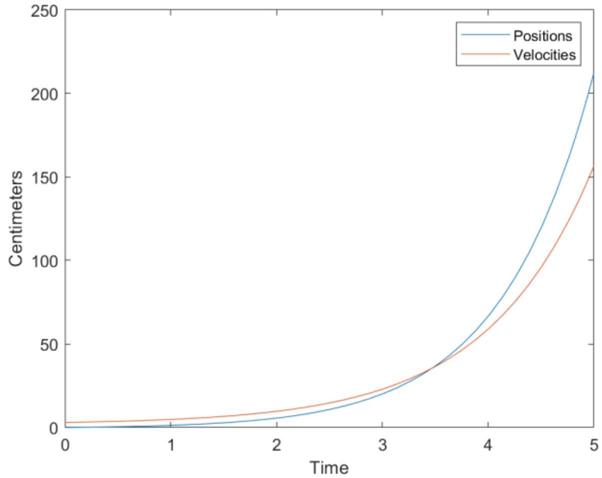

Figure 4. Results of physics simulation

Based on this model, the team concluded that the technology is effective at removing pollutants from the air based on the velocities and positions in the graph above. It is apparent that the technology is capable of cleaning the air at an effective rate, as shown by the high speed of the particle entering the SFT enabling the tower to clean a high volume of air; however, the model is not without its limitations. Some of the assumptions revolve around highly idealized conditions that, while the team believes had minimal effects on the overall findings, may alter the model enough to result in a different conclusion. The most important example of this is the exclusion of wind effects from our model, as the team was not equipped to do the calculations in the time period given. The removal of the assumptions made certainly would increase the accuracy of the model, but it would require more time.

While the technology is effective, it is not without its flaws. One thing that could be investigated is the use of 2 plates in the tower to attract both positively and negatively charged pollutants, as the current design will only attract one or the other, based on the charge of the plate. Additionally, the use of inductors in the SFT have potential to charge neutral pollutants, further increasing the effectiveness of the tower.

Discussion of city wide implementation

In implementing the smog free tower technology to the Hong Kong area, the team wanted to ensure that the towers were constructed in the most critical regions. In order to find which regions were the most critical to implement this technology, the team pulled Air Quality Health Index (AQHI) data from the Environment Protection Department of Hong Kong.

Figure 5. AQHI Rating Index

The AQHI readings are based on $PM_{2.5}$ and PM_{10} particles as well as Ozone, Nitrogen Dioxide, and Sulfur Dioxide. While the focus on the efficacy was mainly around $PM_{2.5}$ and PM_{10} particles, the team believed that overall air quality that included other hazardous materials would be positive to incorporate into the findings. The data provided was the past 9 years of hourly readings. To make sure that readings were consistent, the team took 1 month of each year and compared averages to get relative values to compare each region to. Once the team found the averages, the top 3 cities that were found that would be most necessary to deploy the technology were Causeway Bay, Mong Kok Bay, and Central regions.

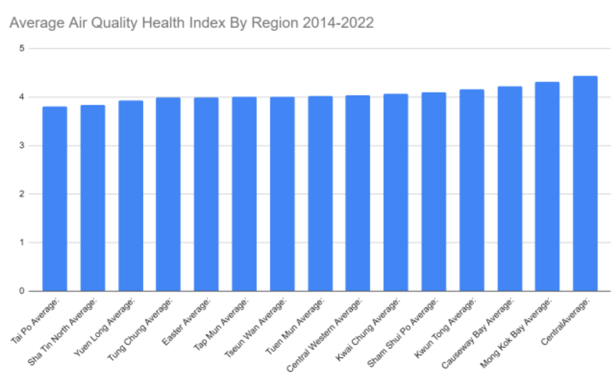

Figure 6. Air Quality Health Index by region

Causeway Bay Average:	4.220824
Mong Kok Bay Average:	4.315675
Central Average:	4.430323

Figure 7. AQHI for specific regions

In finding out how many towers the government of Hong Kong would be able to feasibly purchase, the team calculated an average cost of around 1.8 million dollars. According to the Honk Kong Environment Protection Department budget sheet, they have over 2.4 billion dollars allocated just for ventures related to improving air quality. As a result, it was estimated that the team would be able to deliver 1000 units of a 2m x 2m x 10m (40 m^3) tower.

Figure 8. Wind vector map for Hong Kong to track movement of pollutants

With this in mind, the team was able to estimate roughly that Hong Kong would theoretically be able to be cleaned to a minimum standard given by the World Health Organization in around 3.4 years. In relation to where the towers should actually be situated, the team found that areas by the port, along the highway, and other high density areas within these cities would be most optimal. In addition, the team discussed potentially deploying the towers along the East coast of Hong Kong and catching the particles in a net. This was discussed by analysis of wind position and velocity vector data seen above.

With any large scale change, there must be scaling and sustainability concerns. For this problem in particular, the main concerns deal with maintenance and long term costs. In terms of maintenance, there are some issues with the location and overall weather of Hong Kong. Since the region sits on the shore of a large body of water, the land is susceptible to extreme weather events. Lightning storms, and high winds are a risk for the SFT. This means that the towers should be sturdy enough to withstand high winds, while also made of some material that will not act like a lightning rod.

In addition, issues arise with the various densities of smog in different parts of the city. Since different towers will be cleaning air with different densities of PM_{10} and $PM_{2.5}$, there must be regular check ups on the towers to see if parts need to be replaced or cleaned. Obviously, this will cost government time and resources, so it is important that it is factored into the overall cost.

Long term issues mainly include general wear and tear of the tower and its components, which can be included in the regular check ups during maintenance. One problem in particular is cathode charge reduction. Since the team uses a positively charged plate to push the PM_{10} and $PM_{2.5}$ particles, inevitably some negatively charged particles will come and stick to the plate reducing its overall charge.

Finally, there is a problem with long term powering. Fortunately, the team's design does not require much power to operate. The power that it does require can be provided by solar panels attached to the tower. The solar panels would need to store up some initial energy to start the system, but once started, the energy costs would remain relatively low.

Conclusions and Recommendations

Overall, the team has found that the smog free tower technology would be able to effectively alleviate the poor air quality in Hong Kong. Modeling the technology further provided optimism of the technologies benefit in the applications of usage in the crisis. With the recommended implementation in critical regions, the team was able to estimate that Hong Kong could reach moderate levels of air quality in less than 5 years. When calculating costs, the team was able to come up with a cost that was feasible for the government given their budget size indicated in the report before. Factored into the cost was reliable energy sources such as solar panels to provide long term and effective energy for the charged plates. In addition, the usage of strong materials that would be resistant to weather elements were also taken into account as the region is known for extreme conditions. As a result, the team recommends the government of Hong Kong and the Environment Protection Department of Hong Kong to strongly consider implementing the technology and team’s design as it optimizes particle collection, cost, durability, and efficiency.

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