

EN3004 - Air Pollution Control Engineering AY20/21 S2

Q1) Assume Temperature $T = 25^\circ\text{C}$

a) Pollutant 1 Ozone: (0.30 ppm)

$$\begin{aligned} \text{AQI} &= \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}} (C_p - BP_{LO}) + I_{LO} \\ &= \frac{300 - 200}{0.374 - 0.124} (0.30 - 0.124) + 200 \\ &= 270.4 = \mathbf{271} \end{aligned}$$

Pollutant 2 CO: (12.4 ppm)

$$\begin{aligned} \text{AQI} &= \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}} (C_p - BP_{LO}) + I_{LO} \\ &= \frac{200 - 150}{15.4 - 12.4} (12.4 - 12.4) + 150 \\ &= 150 \end{aligned}$$

Pollutant 3 NO_2 : (1.00 ppm)

$$\begin{aligned} \text{AQI} &= \frac{1.00}{1.24} \times 300 \\ &= 242 \end{aligned}$$

Pollutant 3 SO_2 : $392 \mu\text{g}/\text{m}^3$
convert $\mu\text{g}/\text{m}^3$ to ppm.

$$\begin{aligned} \mu\text{g}/\text{m}^3 &= \text{ppm} \times \text{M.W} \times \frac{P}{RT} \\ 392 &= \text{ppm} \times 64 \times \frac{1 \times 1000}{0.082 \times (273 + 25)} \\ \text{ppm} &= \frac{392 \times 0.082 \times (273 + 25)}{64 \times 1000} \\ &= 0.14986 \text{ ppm.} \end{aligned}$$

Pollutant 5 $\text{PM}_{2.5}$: ($100 \mu\text{g}/\text{m}^3$)

$$\begin{aligned} \text{AQI} &= \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}} (C_p - BP_{LO}) + I_{LO} \\ &= \frac{200 - 150}{150.4 - 65.4} (100 - 65.4) + 150 \\ &= 170.4 = 171 \end{aligned}$$

$$\begin{aligned} \text{AQI} &= \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}} (C_p - BP_{LO}) + I_{LO} \\ &= \frac{150 - 100}{0.224 - 0.144} (0.14986 - 0.144) + 100 \\ &= 103.6 = 104 \end{aligned}$$

Pollutant 6 PM_{10} : ($305 \mu\text{g}/\text{m}^3$)

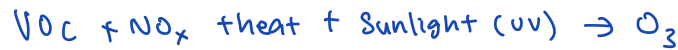
$$\begin{aligned} \text{AQI} &= \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}} (C_p - BP_{LO}) + I_{LO} \\ &= \frac{200 - 150}{354 - 254} (305 - 254) + 150 \\ &= 175.5 = 176 \end{aligned}$$

Since the contributing AQI of Pollutant 1 Ozone is the highest,

the daily Ambient AQI is 271. According to the index, 271 is under very unhealthy levels, but not hazardous.

b) Yes, I agree with them.

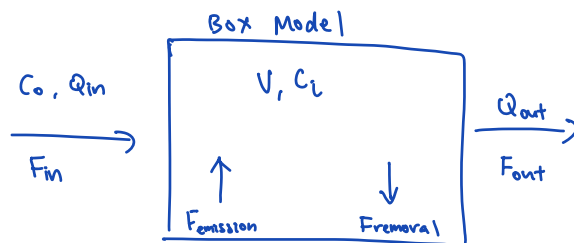
The yellow and brownish color might be due to the formation of ground level ozone due to a chemical reaction between NO_x and VOC_s in the presence of heat and sunlight



c)

Yes, during early morning, the air above the ground is cooled by the cool land. Meanwhile, the sunlight will warm up the air above, causing a layer of warm air above the cool air. This creates a fumigation type inversion layer, trapping the air below, preventing the air below the inversion from dispersing upwards.

d) i) $V = 20 \text{ km}^3$ $C_0 = 5 \text{ ppm}$ $T = 2 \text{ days} = 48 \text{ h}$



$I = 1/h = 24/d$
 Assume $T = 20^\circ\text{C}$, $P = 1 \text{ atm}$.
 convert ppm to mg/m^3
 $C_0 = 6.238 \text{ mg}/\text{m}^3$

$$K = 0.3 / \text{mth}$$

$$= \frac{0.3}{30} = 0.01 / d$$

$$F_{\text{emission}} = 2 \times 32 \times 20$$

$$= 1280 \text{ mg}/d$$

Steady state $C_i = \frac{F_{EM} + IVC_0}{(I+K)V}$

$$= \frac{1280 + 24(20) \times 6.238}{(24 + 0.01) \times 20}$$

$$= 8.90 \text{ mg}/\text{m}^3$$

i) Time taken for CO to reach 90% of steady state concentration

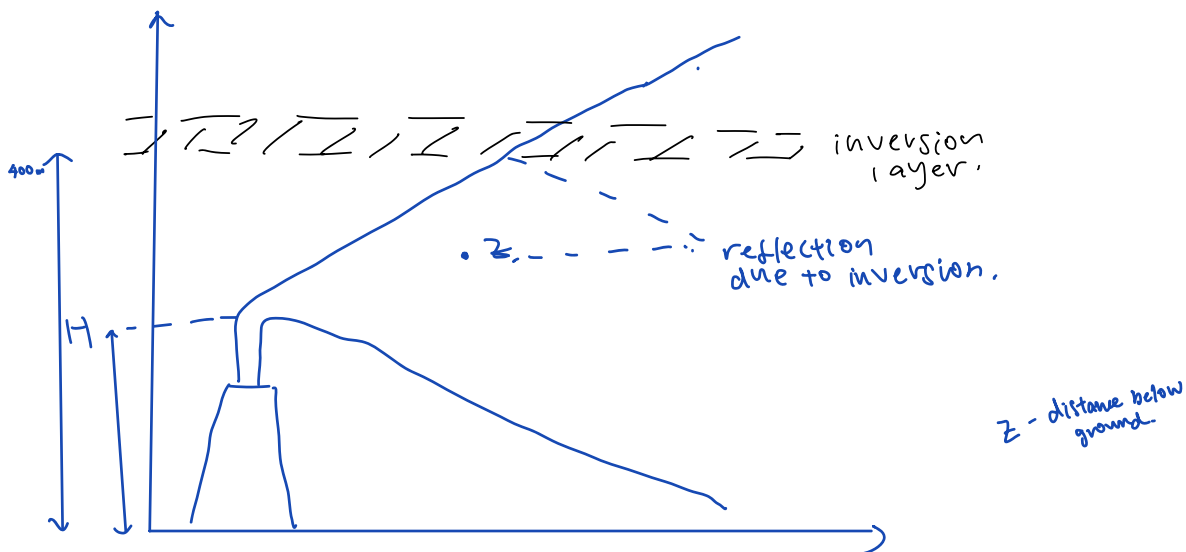
$$e^{-(I+k)t} = e^{-0.9}$$

$$t = \frac{0.9}{I+k}$$

$$= \frac{0.9}{24/d + 0.0/d} \times (24 \text{ h/d} \times 60 \text{ min/h})$$

$$= 54 \text{ mins}$$

2) a) Gaussian Plume model Eqn to account for inversion, but not ground



$$C(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left(\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(400-z)^2}{2\sigma_z^2}\right)\right)$$

b) Using Turner's approx,

$$\sigma_z(x_L) = 0.47(L-H)$$

Plant #1 $x_L = 600 \text{ m}$ stability class = C (slightly unstable) $H = 190 \text{ m}$
 from Pasquill-Gifford curves,

$$\sigma_z = 40 \text{ m}$$

$$40 \cdot (x_L) = 0.47(400 - 190)$$

$$x_L = 2.47 \text{ m}$$

Plant #2 $\sigma_z = 40\text{ m}$, $H = 32\text{ m}$

$$40(x_L) = 0.47(400 - 32)$$

$$x_L = 4.32\text{ m}$$

\therefore Since the x -distance = 600m $>$ x_L , the inversion layer will influence the vertical SO_2 profile over the town.

c) Plant #1

$$C(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \left(\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(400-z)^2}{2\sigma_z^2}\right) \right)$$

Plant #2

$$C(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left(\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(400-z)^2}{2\sigma_z^2}\right) \right)$$

From Pasquill - Gifford Curves,

$$x = 600\text{ m,}$$

$$\sigma_z = 40\text{ m, } \sigma_y = 70\text{ m.}$$

$$\frac{100}{2\pi \cdot 40 \cdot 70 \cdot 4} = 1421\text{ }\mu\text{g}/\text{m}^3$$

d) Plant #1 @ ground level $z = 0\text{ m}$

$$C(x, y, z) = \frac{100}{2\pi \cdot 40 \cdot 70 \cdot 4} \left(\exp\left(-\frac{(-100)^2}{2 \times 40^2}\right) + \exp\left(-\frac{(400)^2}{2 \times 40^2}\right) \right)$$

$$= 0.0179\text{ }\mu\text{g}/\text{m}^3$$

Plant #2

$$C(x, y, z) = 1421\text{ }\mu\text{g}/\text{m}^3 \times \exp\left(-\frac{800^2}{2 \times 70^2}\right) \left(\exp\left(-\frac{(-35)^2}{2 \times 40^2}\right) + \exp\left(-\frac{(400)^2}{2 \times 40^2}\right) \right)$$

$$= 0.09952\text{ }\mu\text{g}/\text{m}^3$$

$$\text{Background conc} = 0.05\text{ }\mu\text{g}/\text{m}^3$$

$$\text{Total } \text{SO}_2 \text{ conc @ Shangri-La} = 0.0179 + 0.09952 + 0.05$$

$$= 0.167\text{ }\mu\text{g}/\text{m}^3$$

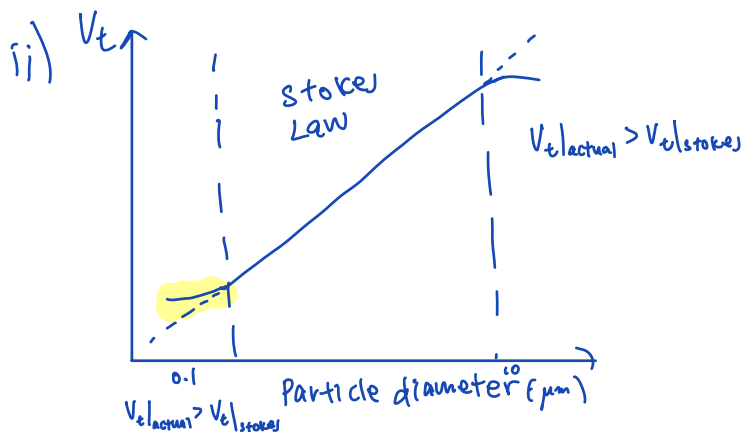
3) a)

Soot particles are generated from combustion process.

Sulfate aerosols, NH_4NO_3 are formed by atmospheric chemical reactions.

b) i) Terminal settling velocity using Stokes' Law

$$\begin{aligned}
 V_t &= \frac{g D^2 \rho_{\text{part}}}{18 \mu} \\
 &= \frac{9.81 \times (0.1 \times 10^{-6})^2 \times 2000}{18 \times 1.8 \times 10^{-5}} \\
 &= 6.05 \times 10^{-7} \text{ m/s} \\
 &= 2.18 \times 10^{-3} \text{ m/h} \\
 &= 2.18 \times 10^{-6} \text{ km/h.}
 \end{aligned}$$



\therefore since $D_{\text{part}} = 0.1$, the actual settling velocity of these particles are higher than the Stokes' terminal settling velocity.

c) i)

x be the efficiency of removal of 1mm particles.

$$10(x) + 100(0.65) + 1000(0.99) = (10 + 100 + 1000)(0.453)$$

$$x = 0.283$$

ii) No. \therefore % removal efficiency = 28.3%
 As seen from the removal efficiency at 10 μm and 1mm, this device is not suited to remove particles smaller than 10 μm , hence not suitable to control indoor $\text{PM}_{2.5}$.

4a) i) Mass of NO = 4250 kg/yr = 11.64 kg/d
 mass of NO₂ = 750 kg/yr = 2.05 kg/d

Assuming complete removal using NH₃,

$$\begin{aligned} \text{mass of NH}_3 \text{ needed for NO} &= \frac{11.64 \times 1000}{14+16} \times (14+3) \\ &= 6.596 \text{ kg.} \end{aligned}$$

$$\begin{aligned} \text{mass of NH}_3 \text{ needed for NO}_2 &= \frac{2.05 \times 1000}{14+16+16} \times (14+3) \times 2 \\ &= 1.515 \text{ kg} \end{aligned}$$

$$\begin{aligned} \text{SNCR efficiency} &= \frac{4}{1.515 + 6.596} \times 100\% \\ &= 49.3\% \end{aligned}$$

ii) Since the boiler operates at high temperatures, SNCR is suitable for use to remove NO_x while the boiler is in operation. It complements the existing SCR system which operates at a lower temperatures.

b) Particulates with diameter < 5µm. → ESP settlers (cut diameter: 0-5µm)

ESP settlers use electrostatic force to collect particles. Particles can be collected dry, which is suitable since there is no sludge disposal facility in the factory. It has high collection efficiency for small particles.

Volatile organic solvents (VOCs) can be removed and recovered through condensation. Since the concentration of VOCs is high, it will be more economical and sustainable to recover these VOCs. A cooler can be used to cool the waste gas stream, and collect the condensed VOCs using a phase separator and reduce the concentration of VOCs in the outlet gas stream.