# AIR

By Ir SW Pang

# Syllabus

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# 1. Nature of Atmospheric Pollution

1.1 Physical structure & composition of the troposphere & stratosphere

1.1.1 Temperature, pressure, density, spatial and temporal relationships

1.1.2 Radiation

- *Important parameters characterising the atmosphere*
- *Atmosphere layers: defined in accordance with the variation of temperature, pressure, density with height: troposphere, stratosphere, mesosphere, thermosphere*
- *Significance of radiation on the atmosphere*
- *The differential heating of the earth's surface results in different weather patterns*

# 1. Nature of Atmospheric Pollution

1.2 Natural composition of the atmosphere (gases, particulates, aerosols, moisture)

1.2.1 Typical concentrations of common species in the natural background

1.2.2 Typical concentrations of common pollutants in polluted environments

- *E.g., Hong Kong (2016): $SO_2$, $NO_2$, CO, $O_3$, $PM_{10}$, $PM_{2.5}$ (1-h max): 133, 353, 3,130, 347, 249, 133 $\mu g/m^3$, respectively*

1.3. Air pollutants

1.3.1 Definitions & characteristics (physical and chemical)

- *Airborne substances that threatens human health, animals, vegetation, structures, environment*
- *Primary (directly emitted) vs secondary (not directly emitted; more difficult to control) air pollutants*

1.3.2 Particulates

- *TSP, $PM_{10}$, $PM_{2.5}$; $SO_4$, $NO_3$, organic aerosols, dioxins, etc*

1.3.3 Gaseous pollutants

- *CO, $CO_2$, $SO_2$, NOx, $O_3$, VOC, CFC, etc.*

# 1. Nature of Atmospheric Pollution

## 1.3.4 Toxic air pollutants

- *TAP/HAP vs common air pollutants*
- *Air pollutants known or suspected to cause serious, irreversible effects*
- *187 HAPs designated by USEPA; 30 urban air toxics (e.g. As, Be, Hg, benzene, 1,3-butadiene, PAH, dioxins) have greatest potential health threat in urban areas.*

## 1.3.5 Threshold and non-threshold pollutants

- *Threshold pollutants: with a level below which no ill effects are observed; e.g., CO*
- *Non-threshold pollutants: no such level/threshold, e.g, $PM_{2.5}$, $PM_{10}$, $O_3$, benzene, PAH, dioxins, etc ); acceptable/tolerable levels are determined by risk.*
- *Different approaches in setting the "acceptable" levels*

# 1. Nature of Atmospheric Pollution

## 1.3.6 Radionuclides

- *Elements that decay and emit energy (γ-ray, α-, β-particles)*
- *Releases during fallouts (e.g., I-131,Pu-239), etc.*
- *Indoors: radon (from Ra in granite materials)*

## 1.3.7 Biological contaminants

- *E.g., pollens, moulds, bacteria, viruses*

## 1.3.8 Odour

- *Some pollutants are odorous,*
- *E.g., $H_2S$ (rotten egg smell), $O_3$ (fishy smell), $NH_3$ (sharp pungent smell), $CS_2$ (ether like smell), etc.*

# 1. Nature of Atmospheric Pollution

## 1.4 Physical and chemical pollutant processes

### 1.4.1 Transport, dispersion, dilution, transformation, scavenging and atmospheric lifetimes.

- *Transport, dispersion by air motion or wind*
- *Dilution or mixing by diffusion due to atmospheric turbulence and concentration difference*
- *Transformation and scavenging processes*

### 1.4.2 Meteorological effects: influence of solar radiation and wind fields, lapse rate and stability conditions

- *Significance of wind speed, wind direction*
- *Relationship of atmospheric pressure and wind: general circulation of the atmosphere; wind speed and direction; cyclones, anticylones, frontal systems, and air masses*
- *Effects of other meteorological factors (rainfall, humidity, solar radiation, cloud cover, etc.)*
- *Influence of topographic features*

# 1. Nature of Atmospheric Pollution

## 1.4.2 Meteorological effects: influence of solar radiation and wind fields, lapse rate and stability conditions *(Cont'd)*

- *Lapse rates (superadiabatic, adiabatic, subadiabatic)*
- *Atmospheric stability - importance of turbulence for dispersing air pollution*
- *Mixing depth/height*
- *Plume rise and plume behaviour under different stabilities: coning, looping, fanning, lofting, fumigation*
- *Temperature inversion: the meteorological conditions most susceptible to high air pollution; Causes and types of inversion: radiation, subsidence, frontal*

## 1.4.3 Spatial and temporal variation of air pollutant concentrations

# 1. Nature of Atmospheric Pollution

## 1.5. Local, regional and global air pollution

- *Two major issues in Hong Kong: (i) local (roadside) air pollution; (ii) regional (PRD) air pollution*

### 1.5.1 Photochemical air pollution

- *Secondary pollutants ($O_3$, $NO_2$, PAN, etc.) produced by the action of sunlight on reactive hydrocarbons / VOC and NOx.*
- *Precursors and chemistry*
- *Meteorological conditions that favour photochemical oxidation (e.g., calm, clear, hot and sunny days before approaching of typhoons)*
- *Diurnal variation: typical peak concentrations in the afternoon*

# 1. Nature of Atmospheric Pollution

## 1.5.2 Acid rain

- *Basics: acidity, pH (unpolluted air vs acid deposition), wet and dry deposition*
- *Causes, responsible air pollutants (e.g., $SO_2$ -> $H_2SO_4$/$H_2SO_3$), $NO_2$ -> $HNO_3$/$HNO_2$)*
- *Effects: Aquatic ecosystems; terrestrial ecosystems; soil and vegetation; human health; materials and visibility*
- *Responses and mitigation action*

## 1.5.3 Long range transportation

- *Acid rain, photochemical air pollution;*
- *Dust storms and transportation of fine particulates, e.g., the Asian dust; etc.*

# 1. Nature of Atmospheric Pollution

1.5.4 Global scale pollutants (greenhouse gases and climate change; stratospheric ozone depletion and ozone depleting substances; persistent organic pollutants)

*Global warming:*

- *Causes; Greenhouse gases (e.g., $CO_2$, $CH_4$, halocarbons, $N_2O$, $O_3$, aerosols); Global warming potentials; Sources of GHG; Emission and GHG trends, IPCC's scenarios; Possible adverse impacts; Global responses - UNFCCC, Kyoto Protocol, Paris Agreement*

*Stratospheric ozone depletion:*

- *Ozone layer (good $O_3$) as a UV protective shield;*
- *Causes of $O_3$ depletion; $O_3$ hole; $O_3$ depleting substances (ODS; e.g., CFC, HCFCs, halons, methyl bromide, etc) and their sources; Impacts of increased UV exposure; Global responses: Vienna Convention, Montreal Protocol*

*Persistent organic pollutant (POP):*

- *Issues; Global responses: Stockholm Convention; Mercury: Minamata Convention*

# 1. Nature of Atmospheric Pollution

## 1.6. Indoor air pollution

- *Major indoor air pollutants (e.g., PM, $NO_2$, HCHO, $CO_2$, moulds, bacteria) sources and sinks*
- *Health issues: Sick building symptoms, building related illnesses, Legionnaires' diseases; respiratory illnesses;*
- *IAQ improvement: Ventilation (natural/mechanical; air changes, ventilation rates); Source control/removal, e.g., banning of cigarette smoking, high VOC paints and furnishings; Air cleaning/purification, etc.*
- *General understanding of the Hong Kong Indoor Air Quality Certification Scheme - 12 parameters to be certified ($CO_2$, CO, $O_3$, $NO_2$ , $PM_{10}$, HCHO, TVOC, bacteria, radon , temp, RH, air movement); IAQ guidelines.*

# 2. Air Pollution Sources and Impacts

## 2.1 Anthropogenic sources of air pollution

### 2.1.1 Stationary

- *Point sources: e.g., power plants, petroleum refining, chemical, cement manufacturing, concrete batching, steel production, incinerators, etc.*
- *Area sources: e.g., restaurants and food cooking, domestic and commercial sources*

- *$SO_2$: combustion of S-containing fuel (e.g., coal, heavy oil)*
  *NOx: oxidation of $N_2$ during combustion*
  *PM: combustion, incineration, dusty material (e.g., cement, rock crushing) handling, food cooking, etc.*
  *VOC: VOC material (e.g., paint, printing ink, organic solvent) manufacturing/storage/handing; petrol filling stations, etc.*

# 2. Air Pollution Sources and Impacts

## 2.1 Anthropogenic sources of air pollution

### 2.1.2 Mobile

- *Vehicles, vessels, aircraft, non-road mobile machinery (NRMM)*
- *Vessels: biggest emission source in Hong Kong*
- *Vehicles: bigger impact due to proximity to receptors*

- *$SO_2$: combustion of S-containing fuel (e.g., vessels)*
  *NOx: oxidation of $N_2$ during combustion (e.g., diesel vehicles, vessels, NRMM)*
  *PM: combustion (e.g., diesel vehicles, vessels, NRMM)*
  *VOC: combustion, vaporisation (e.g., petrol vehicles)*
  *CO: combustion (e.g., petrol vehicles)*

### 2.1.3 Fugitive and non-fugitive

- *Fugitive sources: without well-defined exhausts (e.g., paved/ unpaved road dust; VOC leakage from vents, valves; odour from landfills*

# 2. Air Pollution Sources and Impacts

2.2 Natural sources of air pollution

2.2.1 Volcanoes, wild fires, earthquakes, etc.

- *Some tree and plant species (e.g., Oak trees): isoprene and other VOC:*

2.3 Receptors (human, animal, plant, materials, atmospheric processes)

2.4 Source/Receptor relationships (spatial and temporal)

- *Spatial distribution: In general, other than secondary air pollutants (e.g., $O_3$), the concentration is proportional to the strength of emissions and higher concentrations at receptors close to the sources.*

- *Temporal variations (diurnal, weekday-weekend, seasonal variations, long term trend) and the major factors responsible for these variations*

# 2. Air Pollution Sources and Impacts

## 2.5. Adverse effects

### 2.5.1 Health effects (mortality, morbidity, respiratory illness, sub-clinical effects)

- *Major adverse effects associated with common air pollutants; organs mostly affected by air pollution; vulnerable sub-population: e.g., children, asthmatics, elderly*

- *Eye, skin irritation: $O_3$, $NO_2$, PAN, HCHO, oxidants, etc.*
- *Cardiovascular system: CO, Pb, $PM_{2.5}$/$PM_{10}$ , etc.*
- *Respiratory system (bronchitis, pulmonary emphysema, lung cancer, bronchial asthma, respiratory system infections, etc.): SO2, $O_3$, $NO_2$, $PM_{2.5}$/$PM_{10}$, etc.*
- *Others: brain, nervous system, reproductive system: TAP, etc.*

- *PM: Significance of particle sizes on health*

- *Pollutants associated with the largest long-term and short-term health impacts in Hong Kong and urban, rural areas*

# 2. Air Pollution Sources and Impacts

2.5.2 Ecological impacts, vegetation and forest deterioration

- *Major effects and concerned air pollutants (e.g., $O_3$, $SO_2$, NOx, fluorides, PAN, etc.)*

2.5.3 Materials corrosion

- *Major effects and concerned air pollutants*

2.5.4 Lake acidification

- *Major effects of acidity changes in soil, lake and fresh water and concerned air pollutants*

2.5.5 Others

- *Visibility and major air pollutants (e.g., $PM_{2.5}$, $NO_2$) responsible for visibility impairment*
- *Odour nuisance and factors relevant to odour nuisance*

# 2. Air Pollution Sources and Impacts

## 2.6. Health impact assessments, economic impact assessments, air toxics and risk assessments (e.g., cancer burden, acute, chronic)

- *Characterize, quantify, assess human health and environmental risks associated with exposure to air pollution.*
- *Scientific studies of adverse health effects of air pollution: e.g., Epidemiological studies; Toxicological studies*
- *Excessive health risks: %ER = ($e^{\beta C}$ – 1) x 100%*
- *Life expectancy (L); Years of life loss (YLL; L x No. of deaths due to condition), Years lived with disability (YLD; No. of incidences in the population x disability weight x average duration of condition); Disability adjusted life year (DALY = YLL + YLD)*
- *Value of life: Willingness to Pay (WTP); Value of statistical life (VSL), Value of statistical life year (VSLY)*
- *Quantification of the costs, benefits of health and environmental damages/improvements*

# 3. Air Pollution Modelling

3.1 Purposes of for air pollution modelling (Environmental Impact Analysis, plant siting, emergency response planning, accidental release, public relations, economic impacts)

3.2. Levels of modelling effort (screening, planning, compliance)

- *Purposes: Simulate ambient pollution concentrations under different scenarios; Determine contributions from different sources; Augment the air quality monitoring for assessing AQO compliance status; Support air pollution forecasting; Support EIA, plant siting and regulatory requirements; etc.*

- *Screening models: provide conservative estimates of the air quality impact*
- *Refined models: proper air quality assessment, planning and compliance evaluation.*

# 3. Air Pollution Modelling

## 3.3 Types of air pollution models

- *Major features, assumptions, application, limitations*

### 3.3.1 Box, Gaussian Dispersion:

- *Box model:*

  $C = Q \times L / (H \times u)$

- *Gaussian dispersion model:*

  *A simple solution to the dispersion*
  *Assumes constant emissions under steady-state meteorological conditions;*
  *Dilution is inversely proportional to the wind speed;*
  *Turbulent diffusion is a random activity and hence pollutant concentrations can be taken as normally distributed*

# 3. Air Pollution Modelling

## 3.3 Types of air pollution models

### 3.3.2 Photochemical

- *Simulate the changes of pollutant concentrations over large spatial scales using a set of mathematical equations characterizing the chemical transformation and physical processes and removal process (e.g., deposition) in the atmosphere.*

- *E.g.: Comprehensive Air Quality Model with Extensions (CAMx); Community Multiscale Air Quality (CMAQ) Modeling System.*

# 3. Air Pollution Modelling

## 3.3 Types of air pollution models

### 3.3.3 Physical, CPD models

- *Physical model: simulation of the physical process on a smaller scale by the use of wind tunnel or other fluid modelling facilities.*

- *Computer fluid dynamics (CFD) model: solve the partial differential equations representing atmospheric dispersion phenomena by numerical integration techniques*

### 3.3.4 Receptor models

- *Mathematical or statistical procedures for identifying and quantifying the sources of air pollutants at a receptor location.*
- *E.g., Chemical mass balance, Positive matrix factorization*

# 3. Air Pollution Modelling

## 3.4 Emission inventory and emission modelling

- *Essential part of the air quality management and air quality modelling*

  *E = A x EF x (1 - C x RE)*

  *where: E = emission estimate for the process*
  *A = activity level*
  *EF = emission factor assuming no control*
  *C = control efficiency*
  *RE = regulatory effectiveness*

- *Choice of emission factors and other parameters*

- *Allocation of emissions spatially and temporally*

# 3. Air Pollution Modelling

## 3.5 Model limitations, assumptions, accuracy

- *Sources of uncertainty:*
  *E.g., (i) the input data errors, (ii) model uncertainties e.g., chemical rates, uncertainties in the science on which the model is based, and (iii) uncertainties in transforming of the science into numerical form.*

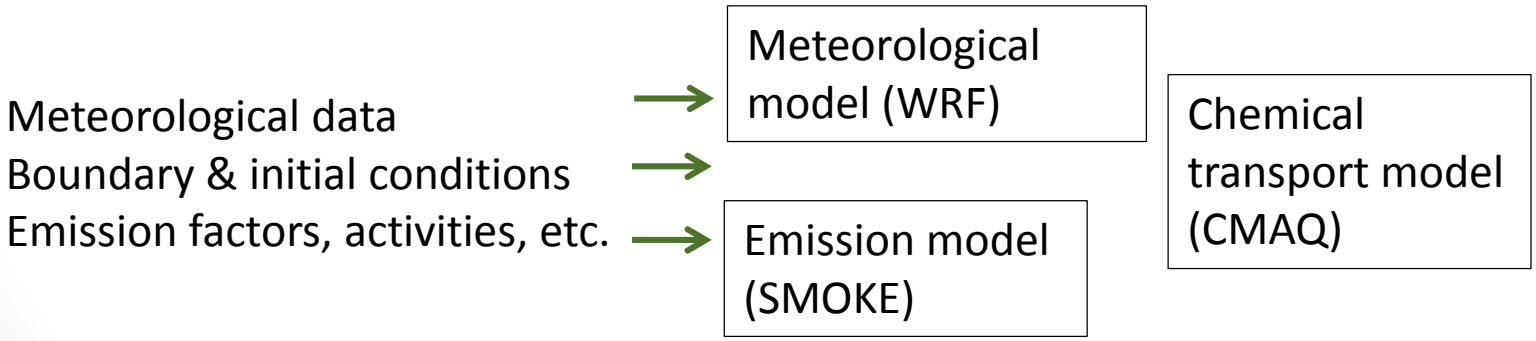
- *E.g., Gaussian model: assume constant wind speed and direction; ignores obstacles, difficult terrains; not applicable for calm wind conditions; applicable within 50 km from the source*

# 3. Air Pollution Modelling

## 3.6 Source / Receptor relationships

- *Receptor-oriented models (e.g., CMB, PMF): identify and quantify source by analyzing the chemical composition of the air pollutants at the receptors*

- *Emission-based models (e.g., HKEPD's PATH-2016): Use best estimates of the emission rates and of meteorology to estimate air pollutant concentrations at various receptors. Modern air quality modelling system:*



# 3. Air Pollution Modelling

## 3.7 Air quality forecasting

- *Helps the public, in particular, the susceptible groups to better prepared before and during air pollution episodes*

- *Emission-based air pollution models*
- *Multi-linear regression and other statistical techniques*
- *Forecaster's own experience*

# 4. Air Quality Management Strategies

## 4.1 Air pollution prevention versus control

- *Prevention is better than care: e.g., (i) reducing polluting activities; and (ii) sustainable policy (e.g., clean energy, traffic management, pedestrian/cycling friendly, etc.)*
- *Control/management approaches: AQM strategies, their philosophies, practices, applications, advantages/ disadvantages*

## 4.2 Best practicable means / best available control technology, technology forcing approach

- *Requiring the maximum emission control to achieve cleanest possible air;*
- *Simple and but cannot guarantee air quality is acceptable*
- *E.g.: emission limits; control of specified processes / use of BPMs; requiring new vehicles to meet the most stringent Euro standards, etc.*

# 4. Air Quality Management Strategies

## 4.3 Air quality standards approach and criteria pollutants

- *Designates acceptable pollution levels, i.e., AQOs; and achieves these levels through emission control programmes;*
- *E.g.: promulgation of AQOs; "Clean Air Plan" issued in March 2013 by the ENB in collaboration with THB, FHB and DEVB; the EIA process.*

## 4.4 Market-based mechanism, emission trading, emission offsetting

- *Determines the total permissible amount of emissions and allow the polluters to determine and implement their most cost-effective means for ensuring the total emissions will not exceed the quantity of these emission allowances;*
- *E.g.: US Acid Rain Programme; HK/PRD power plant emission trading; Emission tax / pollution charge*

## 4.5 Cost-benefit approach

- *Pollution control option(s) which minimizes the sum of pollution damage and pollution control costs will be adopted*

# 4. Air Quality Management Strategies

4.6 Socio-economic and political issues, polluter pays principle

- *Observation of the polluter pays principle, environmental equity principle, sustainability principle, etc. and; ensuring greatest cost-effectiveness.*

4.7 Regulatory and non-regulatory approaches

- *Regulatory: simple, effective and easy to implement and enforce;*
- *Non-regulatory: quick implementation without going statutory process; e.g., Voluntary compliance and reporting of non-compliance cases; Promoting polluters' environmental awareness and encourage process changes; Public recognition of the participants; Labelling of low emission products or facilities; Incentives (e.g., tax or fee reduction)*

# 4. Air Quality Management Strategies

4.8. Air quality and emission limits, air pollutant nuisance, prevention of significant deterioration

- *AQOs (primary vs secondary), emission limits, PSD increments, nuisance criteria, and their purposes and establishment / review processes.*

| Pollutants | Average Time | HK AQOs (1987) | *WHO Interim Targets* | | | *WHO AQGs* | No. of Exceedances Allowed |
|---|---|---|---|---|---|---|---|
| | | | IT-1 | IT-2 | IT-3 | | |
| | | $\mu g/m^3$ | | | | | |
| Sulphur dioxide ($SO_2$) | 10-min | - | - | - | - | 500 | 3 |
| | 24-hr | 350 | 125 | 50 | - | 20 | 3 |
| Nitrogen dioxide ($NO_2$) | 1-hr | 300 | - | - | - | 200 | 18 |
| | Annual | 80 | - | - | - | 40 | NA |
| Carbon monoxide (CO) | 1-hr | 30,000 | - | - | - | 30,000 | 0 |
| | 8-hr | 10,000 | - | - | - | 10,000 | 0 |
| Ozone ($O_3$) | 8-hr | - | 160 | - | - | 100 | 9 |
| Respirable suspended particulates ($PM_{10}$) | 24-hr | 180 | 150 | 100 | 75 | 50 | 9 |
| | Annual | 55 | 70 | 50 | 30 | 20 | NA |
| Fine suspended particulates ($PM_{2.5}$) | 24-hr | - | 75 | 50 | 37.5 | 25 | 9 |
| | Annual | - | 35 | 25 | 15 | 10 | NA |
| Lead (Pb) | Annual | - | - | - | - | 0.5 | NA |

HK AQOs (2014)

# 4. Air Quality Management Strategies

4.9. Dissemination of air quality information; air quality index/air quality health index

4.10. Education and public awareness of air pollution

- *To enhance public awareness on air pollution, etc.*
- *Air Quality Health Index (AQHI):*
  *3-hour rolling average concentrations of $NO_2$, $O_3$, $SO_2$ , and $PM_{10}$ (or $PM_{2.5}$ whichever the higher).*
  *Based on the sum of additional short-term hospital admission risks (%AR) of respiratory and cardiovascular illnesses*
  *Total %AR = %AR ($NO_2$) + %AR ($SO_2$) + %AR ($O_3$) + %AR (PM)*
  *Threshold for issuing health advice is set at the %AR at their respective short-term WHO*
  *On a scale of 1 to 10 and 10+, grouped into five AQHI health risk categories; health advice given on "high" and above categories*

# 5. Air Pollution Control Technology

## 5.1 Control of emissions from stationary sources

- *Prevent/reduce emissions, e.g., by (a) process/equipment change; (b) fuel/raw material changes (e.g., low S coal, coal to natural gas power generation, low VOC paint); and (c) energy efficiency improvement and conservation;*

- *Control emissions, including proper operation and maintenance (e.g., $SO_2$: flue gas desulphurization/ scrubber; PM: EP, bag filter/baghouse, scrubber; NOx: low-NOx burner, SCR);*

- *Render emission inoffensive or harmless: e.g., by proper chimney dispersion (adequate chimney height / location, exit temperature and velocity).*

# 5. Air Pollution Control Technology

## 5.2 Control of gaseous pollutants

- *Knowledge of the control equipment/ practices that are effective in controlling respective air pollutant emissions; Working principles, Application, Design, operation and maintenance, Limitations*

### Absorption

- *Removes gaseous pollutants by mass transfer of the gaseous pollutant from the gas phase to the liquid phase.*
- *Types of scrubbers: packed towers, spray towers, and venturi scrubbers*
- *Efficiency: depending on contact time, concentration and reactivity of absorbent, etc.*
- *E.g.: FGD; removal of chemical air pollutants (e.g., $H_2S$, HCl)*

# 5. Air Pollution Control Technology

## 5.2 Control of gaseous pollutants (Cont'd)

### Adsorption

- *Removes gaseous air pollutants by adhering them to the surface of a solid, e.g., activated carbon, silica gel, and alumina*
- *Adsorbing systems: "non-regenerative" or "regenerative"*
- *Efficiency: depending on adsorption isotherm, gas retention time, etc.*
- *E.g.: VOCs, toxic organic gases from industrial gas streams; etc.*

### Condensation

- *Converting gaseous air pollutants to liquid by lowering the temperature and/or increasing the pressure.*
- *Condensation systems: direct contact condenser; surface condenser*
- *E.g.: as preliminary devices for reducing the waste gas volume and concentrations of VOCs and other condensable gases*

# 5. Air Pollution Control Technology

## 5.2 Control of gaseous pollutants (Cont'd)

### Incineration

- *Oxidation of gaseous air pollutants with a combustible material in the presence of heat*
- *Incineration systems: thermal (direct flame) incinerator; catalytic incinerator*
- *E.g.: removal of VOCs, organic gases*
- *Efficiency: depending on temperature, turbulence, excess air*

*Comparison with other control equipment:*

*Incineration > carbon adsorption > condensation*

## 5.3 Control of particulate pollutants

- *Knowledge of the control equipment/ practices that are effective in controlling respective air pollutant emissions; Working principles, Application, Design, operation and maintenance, Limitations*
- *Significance of particle sizes*

# 5. Air Pollution Control Technology

## 5.3 Control of particulate pollutants (Cont'd)

### Cyclone and inertia separators

- *Separation of particulates by inertia/centrifugal forces*
- *Efficiency: low for small particles; depending on cyclone diameter, particle diameter and other characteristics; gas velocity, etc.*
- *E.g.: as pre-cleaner ahead of other advanced control devices.*

### Wet scrubbers

- *Liquid (usually water) introduced to increase the particle size and entrap the particles*
- *Types: Spray towers, packed towers and venturi scrubbers*
- *Efficiency: low/moderate; high for venturi scrubbers; depending on droplet size, gas velocity, etc.*
- *E.g.: removal of sticky particulates, as pre-cleaner ahead of other advanced control devices etc.*

# 5. Air Pollution Control Technology

## 5.3 Control of particulate pollutants (Cont'd)

### Electrostatic precipitators

- *Charged particles migrate to the collecting surface through an electrical field created by high DC voltage*
- *Efficiency: >99% or more for ~0.1 to10 μm particulates, depending on gas velocity, collector surface area, etc.*
- *E.g.: power plants, steel manufacturing, cement plants, restaurant (cooking fumes), etc.*

### Baghouses

- *Removes of particulates by passing through a fabric*
- *Cleaning mechanism: shaking, reverse pulse jet cleaning*
- *Efficiency: very high even for small particles depending on gas velocity, air-to-cloth ratio, etc.*
- *E.g.: power plant, incinerators, cement, steel, mineral processing, etc*.

# 5. Air Pollution Control Technology

## 5.4 Combustion control, fuel restriction and control, material restriction and control

- *NOx: reaction between $N_2$ and $O_2$ at high temperature*
- *Reduced by combustion modification: (i) reducing combustion temperature (e.g., low-NOx burner); (ii) decreasing $O_2$ for combination (e.g., low excess air, staged combustion, flue gas recirculation);*
  *Flue gas treatment: selective catalytic reduction (reduction of NOx by $NH_3$ in presence of Ti and V catalysts).*

- *Process/equipment change: e.g., power plant (electricity generation by natural gas, renewable energy)*

- *Fuel material/raw material change: e.g., (low emission coals, ultra-low S (<0.005%) diesel fuel). natural gas (emits almost NOx only); use low VOC paints*

# 5. Air Pollution Control Technology

## 5.5 Control of emissions from mobile sources, including vehicles, automotive, vessels, aircrafts

- *Spark Ignition engines (petrol, LPG), Compression ignition engines (diesel) and their major emissions (SI engines: CO, VOC, NOx, etc; CI engines: PM, NOx, etc)*
- *Air-to-fuel ratio and its effects on emissions*
- *Emission control measures:*
  *Capturing evaporative and crankcase emissions (petrol engines)*
  *Engine modification, exhaust gas recirculation*
  *Fuel change: e.g., diesel to LPG taxis, reformulated petrol, ultra-low S diesel, biodiesel*
  *Tail-pipe exhaust control:*
    *Petrol - three way catalyst (CO, VOC, NOx control)*
    *Diesel - SCR (NOx control); PM filter/catalyst (PM control)*
  *Use of low emission vehicles: Hybrid, LNG, electric vehicles, etc.*
- *Inspection and maintenance (I&M) and their significance*

# 5. Air Pollution Control Technology

## 5.5 Control of emissions from mobile sources, including vehicles, automotive, vessels, aircrafts (cont'd)

*Traffic management:*

- *E.g., low/zero emission zones, road pricing, pedestrianisation, cycling, mass transit, transport planning*

*Vessels:*

- *Largest emission source in Hong Kong*
- *Control measures: clean fuel/electricity, engine upgrading/ replacement, exhaust control (FGD, SCR), etc.*
- *International Maritime Organization and local requirements*
- *Fuel S control; fuel switch while berthing; emission control areas*

*Aircrafts:*

- *Use ground power during parking, engine energy efficiency, alternative fuel, etc.*
- *Requirements of the International Civil Aviation Organization*

# 5. Air Pollution Control Technology

5.6 Management and disposal of waste streams (multimedia)

- *Minimise waste generation*
- *Reuse of wastes;*
- *Observation of the relevant water and waste legislations*

5.7 Emission factors and estimates

5.8 Compliance planning; limits, standards, technology, and documentation

- *Adequate choice of emission factors (e.g., USEPA AP-42) for planning / design*
- *Not only adequate design, provision of control equipment, but also proper operation and maintenance*
- *Implementation of a structured environmental management system*

# 6. Ambient Air & Emission Sampling & Analysis

## 6.1 Ambient air quality monitoring

- *determine highest concentrations, ascertain AQO compliance*
- *representative concentrations for quantifying exposures*
- *identify major emission sources and their impacts*
- *determine background levels*
- *study pollution interactions and patterns*
- *support and evaluate policy*
- *provide data for AQI/AQHI*
- *air pollution trends*
- *validate dispersion models and support health and other studies / researches.*

# 6. Ambient Air & Emission Sampling & Analysis

## 6.1.1 Site selection required for effective and representative sampling

- *Spatial representativeness (micro (<0.1 km), middle (0.1-0.5 km), neighbourhood (0.5-4 km), urban (4-50 km), regional, national, global) is consistent with the monitoring objectives*
- *Air monitoring train design (e.g., USEPA: SLAM, NAMS, PAMS, supersite, PSD, special purposes)*
- *If $O_3$ exceedances observed: photochemical assessment monitoring stations (PAMS) to monitor VOCs, $O_3$, NOx, formaldehyde, acetaldehyde and acetone*
- *Siting requirements of general and roadside air quality stations (e.g., USEPA's siting requirements)*

# 6. Ambient Air & Emission Sampling & Analysis

## 6.1.2 Air quality monitoring system

- *Sampling inlet -> air movers (e.g., pumps) -> sample collection / analysis (grab sampling / continuous monitors) -> flow device -> data acquisition, processing and reporting system*
- *Collection efficiency, sample stability, recovery and minimal interference; use of inert materials (glass, telfon, stainless steel)*
- *Compliance with USEPA's requirements*

## 6.1.3 Air quality monitoring methods: reference and equivalent methods

| Air Pollutant | FRMs | Common Continuous FRMs/FEMs |
|---|---|---|
| $SO_2$ | Pararosaniline method | UV Fluorescence |
| NO, $NO_2$, NOx | Gas phase chemiluminescence | Gas phase chemiluminescence |
| CO | Non-dispersive infrared photometry | Non-dispersive infrared photometry |
| $O_3$ | Chemiluminescence | Chemiluminescence, UV Photometry |
| $SO_2$, $NO_2$, $O_3$ | See above | UV-Differential optical absorption spectroscopy (UV-DOAS) |
| PM | Gravimetric method | tapered elemental oscillating microbalance; β-attenuation sampler |

# 6. Ambient Air & Emission Sampling & Analysis

## 6.2 Meteorological monitoring

- *Parameters, measurement equipment and siting requirements*

  *Wind speed (e.g., by rotating cup anemometer or propeller anemometer, ultrasonic technology);*
  *Wind direction (e.g., by wind vane, propeller anemometers, ultrasonic technology);*
  *Temperature (e.g., by thermocouples, resistance temperature detector, thermistor,)*
  *Solar radiation (e.g., by pyranometer, net radiometer)*
  *Mixing heights (e.g., by Doppler sound detection & ranging systems)*

# 6. Ambient Air & Emission Sampling & Analysis

## 6.3 Emission sampling

- *determine quantity, quality and characteristics of emissions;*
- *measure the efficiency of control equipment*
- *assess the performance of control strategies*
- *determine the effect on the emission due to changes in raw materials and processes;*
- *compliance status; certify the emission reduction in emission trading programmes*
- *developing emissions inventories; etc.*

### 6.3.1 Site selection required for effective and representative sampling

- *Representative sampling location (with laminar gas flow: e.g., 8 D downstream and 2 D upstream; away from obstructions)*
- *Traverse points: especially velocity, PM measurements*
- *Acceptable sampling train and methods*
- *Measurement of other parameters, e.g., temperature, pressure, moisture, humidity and gas composition. sampling*

# 6. Ambient Air & Emission Sampling & Analysis

## 6.3.2 Isokinetic sampling; constant rate and exhaust gas recycling sampling

- *Particulate Sampling - Isokinetic Sampling:*
  *Sampling velocity ($V_s$) = flue gas velocity ($V_g$)*
  *If $V_s > V_g$: inertia of large particles will carry them past the sampling nozzle, leading to negative error*
  *If $V_s < V_g$: inertia of large particles will carry them into the sampling nozzle, leading to positive error*

- *$PM_{10}$/$PM_{2.5}$ Sampling:*
  *Issue: The sampling velocity for achieving desired cut-diameter may not equal to that for maintaining isokineticity*
  *(a) Constant rate sampling with the isokinetic condition met by changing nozzles of different diameters (to maintain equal sampling velocity at each of the traverse points)*
  *(b) Exhaust gas recycling to maintain constant flow rate*

# 6. Ambient Air & Emission Sampling & Analysis

## 6.3.3 Effects of particle size on sampling accuracy

- *Ensuring the cut sizes of particles within acceptable range (e.g., ±1μm for $PM_{10}$ sampling) is very important in particulates sampling, as the mass of a particle is proportional to the cube of its diameter.*

## 6.3.4 Condensable emission monitoring

- *Condensable PM could be significant contributors to ambient $PM_{2.5}$ during plume dispersion*
- *Sampled by dry impingers and a filter after cooling by an ice-water cooled condenser and determined gravimetrically*

# 6. Ambient Air & Emission Sampling & Analysis

## 6.3.5 Continuous emission monitoring (CEMs)

- *To meet the need for ascertain continual compliance and determination of exceedances*

| Working Principle | Category | Gases Measured | USEPA Method |
|---|---|---|---|
| **UV Spectrophotometry** | Extractive | NOx | Method 7B |
| **UV Fluorescence** | Extractive | $SO_2$ | Method 6C |
| **Non-Dispersive IR** | Extractive | CO, $CO_2$ | Method 10 |
| **Fourier Transform IR** | Extractive; Path | Vapour phase organic and inorganic emissions | Method 320 |
| **Flame Ionization Detector** | Extractive | Total organic compounds | Method 25A |
| **Paramagnetic** | Extractive | $O_2$ | Method 3A |
| **Zirconia Oxide Cell** | In situ | $O_2$ | Method 3A |
| **Flame Photometry** | Extractive | S containing gas | Method 16 |

# 6. Ambient Air & Emission Sampling & Analysis

## 6.4 Optical remote sensing

- *Techniques and applications*
- *E.g., UV-DOAS system in monitoring of $SO_2$, $NO_2$ and $O_3$ at some EPD's ambient air quality stations; Open-path Fourier Transform Infrared (OP-FTIR) Spectroscopy; Path-Integrated Differential Absorption LIDAR (PI-DIAL)*
- *Satellite remote sensing*

## 6.5 Instrumentation, data acquisition systems, data reporting

- *Major components*
- *Data reporting: Expressed as at reference conditions (e.g., Ambient concentrations: 20$^{o}$C and 1 atm); Emission concentrations: 0$^{o}$C and 1 atm, dry condition, correction to 15% $O_2$ levels*

# 6. Ambient Air & Emission Sampling & Analysis

## 6.6 Quality control and assurance

- *To ensure: (i) representativeness; (ii) accuracy and precision; (iii) adequate data capture (temporal completeness); (iv) reproducibility; (v) traceability; (vi) consistency (from site to site and over time); and (vii) international comparability*
- *QC programmes: e.g., proper installation and personnel, international recognised methods, calibration, zero/span checks, traceability, preventive maintenance, SOP, etc.*
- *QA programmes: e.g., performance audit, system audit, system review, inter-laboratory comparison, etc.*

## 6.7 Real-time monitoring versus intermittent discreet sampling/analysis

- *Real-time monitoring: capturing worse cases and more useful data; Grab/intermittent samplings are still used for samplings of acid rain, TAP and special studies, etc.*

## 6.8 Health and safety precautions

# Suggested Reading Materials

- Thad Godish, Wayne T. Davis, Joshua S. Fu, *Air Quality*, 5th ed., CRC Press, 2015
- Richard C. Flagan and John H. Seinfeld, *Fundamentals of Air Pollution Engineering,* Dover Publications, Inc., 2012
- Noel De Nevers, *Air Pollution Control Engineering*, 2nd ed., Waveland Pr Inc., 2010
- Environmental Protection Department, HKSAR (Air quality related webpages)
  http://www.epd.gov.hk/epd/english/environmentinhk/air/air_maincontent.html
- A Clean Air Plan for Hong Kong, Environment Bureau, HKSAR
  http://www.enb.gov.hk/sites/default/files/New_Air_Plan_en.pdf
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  http://ec.europa.eu/environment/air/index_en.htm
- US Environmental Protection Agency (Air quality related webpages)
  https://www.epa.gov/learn-issues/learn-about-air
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- US Environmental Protection Agency (Air Pollution Training Institute)
  http://www.apti-learn.net/LMS/EPAHomePage.aspx
- World Health Organization (Air webpages)
  http://who.int/phe/health_topics/outdoorair/en/
- Recommended Study Materials, Text Books & Resources of Qualified Environmental Professional (QEP) Certification, The Institute of Professional Environmental Practice