GENERAL CONCEPTS AND FUNDAMENTALS (I)

DEFINITIONS

“Pollution”: definition

Definition (Directive Industrial Emissions Directive -“IED” 2010/75/EU) :

“means the direct or indirect introduction, as a result of human activity, of substances, vibrations, heat or noise into air, water or land which may:

- be harmful to human health or the quality of the environment,
- result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment”

"Air Pollution": definition

11.6.2008 EN Official Journal of the European Union L 152/1

I

(Acts adopted under the EC Treaty/Euratom Treaty whose publication is obligatory)

DIRECTIVES

DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 21 May 2008

on ambient air quality and cleaner air for Europe

'**ambient air**' shall mean outdoor air in the troposphere, excluding workplaces as defined by Directive 89/654/EEC where provisions concerning health and safety at work apply and to which members of the public do not have regular access.

The indoor air is not treated in this regulation.

“Air Pollution”: definition

Italian law

Decreto Legislativo 3 aprile 2006, n. 152

"Norme in materia ambientale"

pubblicato nella *Gazzetta Ufficiale* n. 88 del 14 aprile 2006 - Supplemento Ordinario n. 96

Art. 1-52	*Artt. 53-108*	*Artt. 109-176*	*Artt. 177-213*	*Artt. 214-266*	*Artt. 267-318*	*ALLEGATI*

PARTE QUINTA

NORME IN MATERIA DI TUTELA DELL'ARIA E DI RIDUZIONE DELLE EMISSIONI IN ATMOSFERA

TITOLO I

ART. 268
(definizioni)

1. Ai fini del presente titolo si applicano le seguenti definizioni:

a) inquinamento atmosferico: ogni modificazione dell'aria atmosferica, dovuta all'introduzione nella stessa di una o di più sostanze in quantità e con caratteristiche tali da ledere o da costituire un pericolo per la salute umana o per la qualità dell'ambiente oppure tali da ledere i beni materiali o compromettere gli usi legittimi dell'ambiente;

“Control”: definition

Means a combination of techniques to prevent and reduce man-made air polluting emissions. (The actions taken or to be taken – to reduce the emissions of pollutants)

TECHNIQUES to be applied to plants listed in Annex I of directive “IED” 2010/75/EU are called “BAT” (Best Available Techniques). *In Annex I you’ll find most polluting industrial activities.*

BAT are reported in official EU documents called Bref (or *Bref*). Free downloading!

- Bref for specific activities (Vertical Bref)
- Bref for generic activities (Horizontal Bref)

The italian term “**Controllo**” is used with the meaning of **Monitoring**!

Sources of air pollution: classification

Mobile sources of pollutants

are from vehicles or engines that can be moved:
On-road sources: cars, light-duty trucks, buses, motorcycles
Off-road sources: boats, airplanes, trains, construction equip.
(Air pollution from shipping is in a different category)

Stationary sources of pollutants

are in a specific location, like a smokestack from a fossil power plant

Line sources of pollutants

are a form of mobile source tracked in one dimension (e.g., from a highway)

Area sources of pollutants

are made up from small emitters but are defined over two dimensions

The MAIN FOCUS of the course is on the **control of air pollution from stationary sources**. Unless very significant, vehicular pollution control equipment is a specialized field limited to vehicle manufacturing companies.

“Emission”: definition

means the direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the installation into AIR, water or land *(From IED)*

Emissions

EMISSION TYPOLOGIES

- **Conveyed and Not-conveyed (diffuse, fugitive , they should be conveyed if possible)**
- **from stationary and mobile sources**

WE MUST REDUCE EMISSIONS OF POLLUTANTS TO THE ATMOSPHERE, through:

- **Prevention** (i.e. cleaner fuels/materials, less fuel consuming cars, ..)
- **Control** (i.e. abatement techniques)

moodle

Introduce in the chat of Moodle one measure of prevention and one of control you know from previous experiences

Exercise 1.1.

Assume an average car in Italy gets 15 km per liter, is driven 15.000 km per year and weighs 1500 kg. Further, assume that gasoline weighs 0,75 Kg per liter and contain 85% carbon by weight.

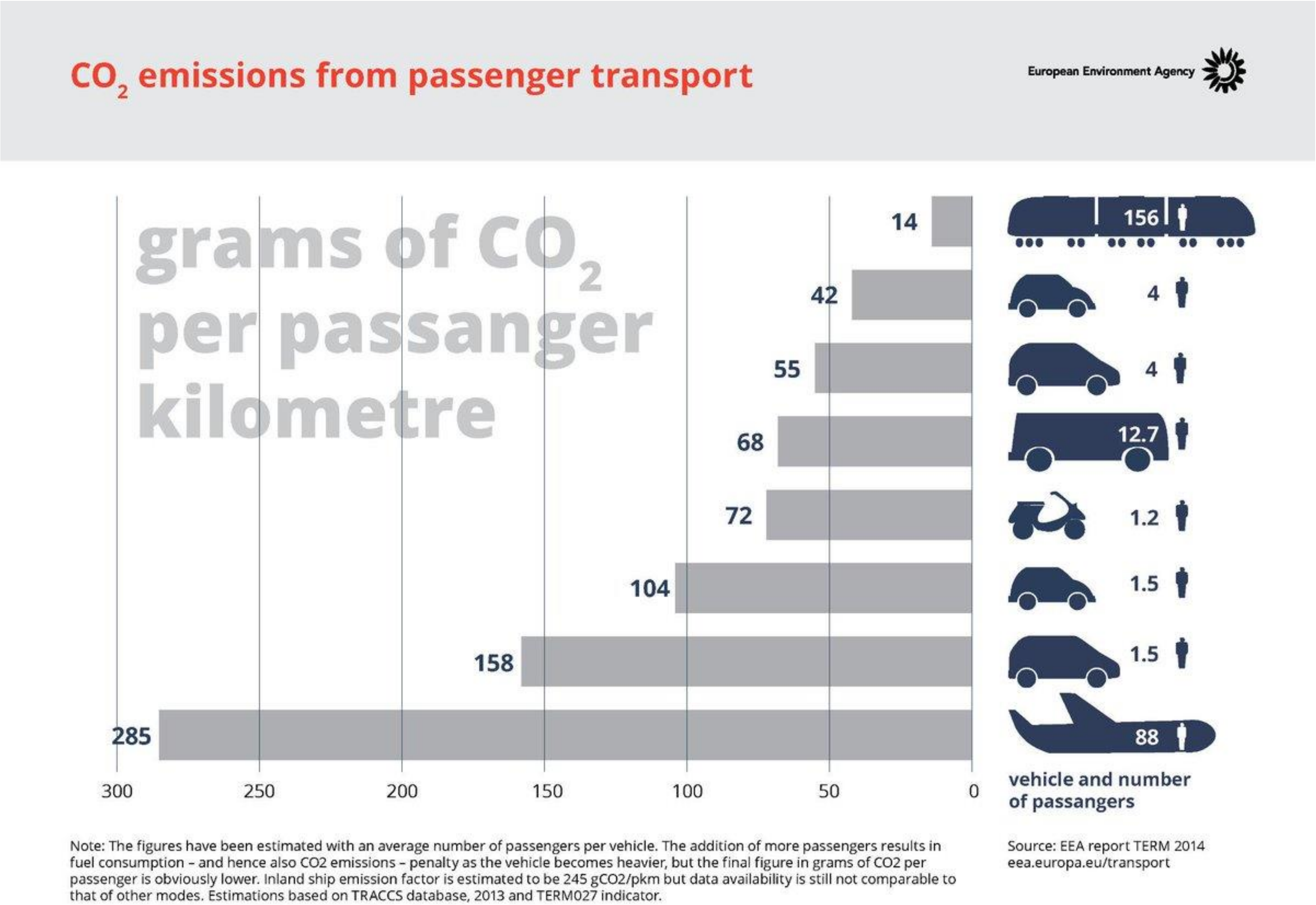
a) Is there any truth to the statement that each car emits its own weight in carbon dioxide each year?

b) Which is the quantity of CO_2 emitted per Km e per person (assume 4 person per vehicle) ?

c) Considering to use the train for the 50% of the travels, which is the reduction in term of CO_2? For the train use a value of 14 g CO_2/km*person.

~1000 kg

CO_2 emissions by transport mode



Carbon sequestration

How many trees in a city are necessary for a carbon sequestration equivalent to the amount emitted yearly by a car (see previous exercise)?
Assume an average C sequestered of 4,5 kg C/year

Which is the cost? Comment the question in moodle

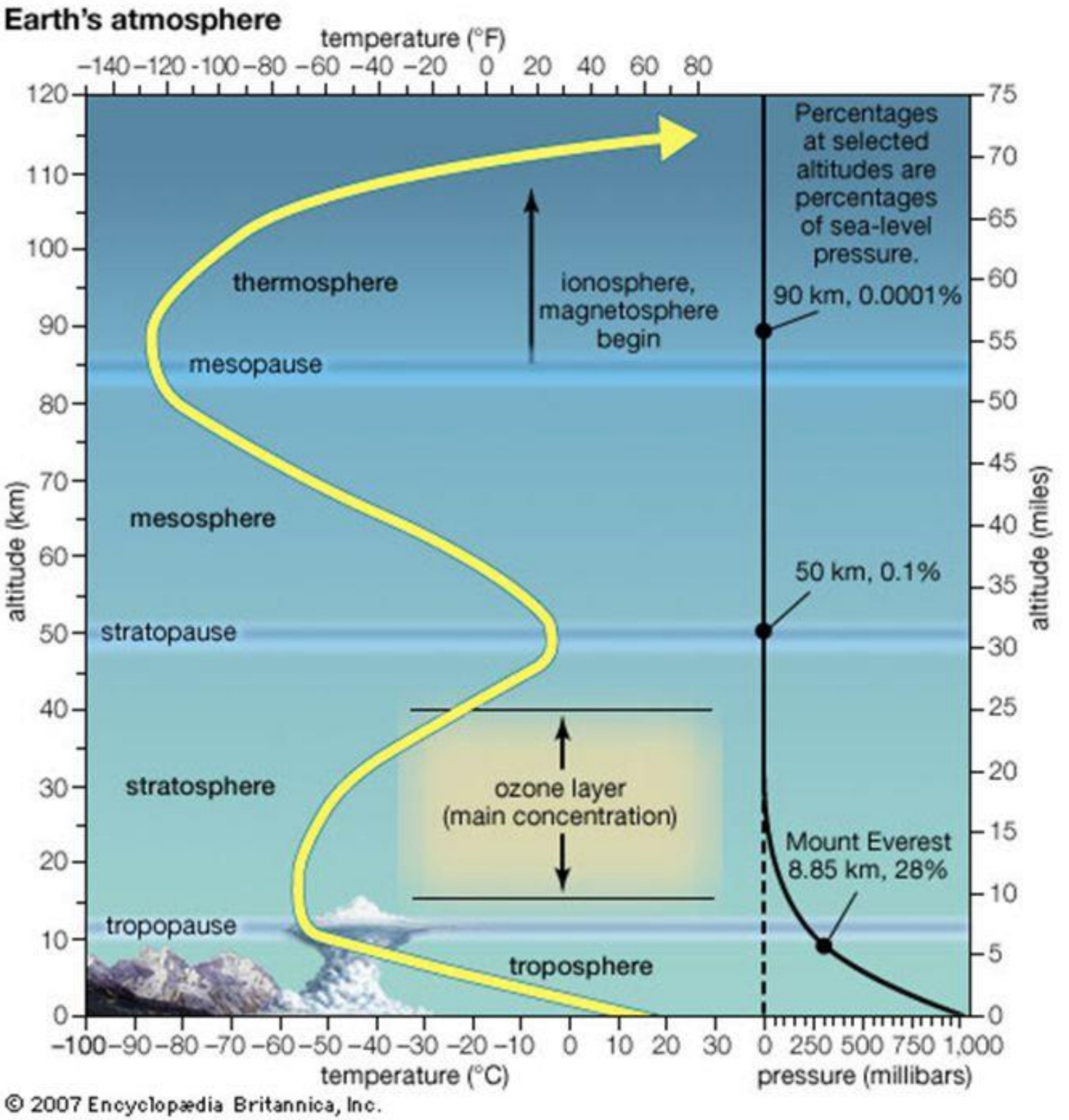
References:
Akbari, H., 2002. Shade trees reduce building energy use and CO_2 emissions from power plants 116, 119–126.

Emission Limit Values (ELV)

Emission Limit Values means the mass, expressed in terms of certain specific parameters, concentration and/or level of an emission, which may not be exceeded during one or more periods of time; emission limit values may also be laid down for certain groups, families or categories of substances.

The emission limit values for substances normally apply **at the point** where the emissions leave the installation, any dilution being disregarded when determining them.

Layer of Atmosphere



AIR:
We will concentrate on the **troposphere**.

Stratosphere is not the focus of this course, but ... We'll pay much attention to it (particularly to the ozonosphere).

Composition of dry unpolluted air

- mostly constant in vol/vol basis
- appreciable and variable water vapor content (humidity) → 3 – 50,000 ppm

Substance	Concentration (ppm)[1]
Nitrogen	780,900
Oxygen	209,400
Argon	9,300
Carbon dioxide	315
Neon	18
Helium	5.2
Methane	2.3
Krypton	0.5
Hydrogen	0.5
Xenon	0.08
Nitrogen dioxide	0.02
Ozone	0.01-0.04

BASIC PROPERTIES OF GAS

Basic properties of gases

Ideal gas law

pV = nRT
p = pressure
V = volume
n = number of moles
T = absolute temperature (°K)
R = universal gas constant (numerical value dependent on units used for P, T, V and n)

Avogadro's rule

At T=0°C (273 K) and P=1 atm (101,3 kPa)
1 mole of any ideal gas has a volume of 22,4 l

Values of R	Units (V P T −1 n−1)
8.3144598(48)	kg m2 s−2 K−1 mol−1
8.3144598(48)	J K−1 mol−1
8.3144598(48) ×10−3	kJ K−1 mol−1
8.3144598(48)×107	erg K−1 mol−1
8.3144598(48)×10−3	amu (km/s)2 K−1
8.3144598(48)	**m3 Pa K−1 mol−1**
8.3144598(48)×106	cm3 Pa K−1 mol−1
8.3144598(48)	L kPa K−1 mol−1
8.3144598(48)×103	cm3 kPa K−1 mol−1
8.3144598(48)×10−6	m3 MPa K−1 mol−1
8.3144598(48)	cm3 MPa K−1 mol−1
8.3144598(48)×10−5	m3 bar K−1 mol−1
8.3144598(48)×10−2	L bar K−1 mol−1
83.144598(48)	cm3 bar K−1 mol−1
62.363577(36)	L Torr K−1 mol−1
1.9872036(11)×10−3	kcal K−1 mol−1
8.2057338(47)×10−5	**m3 atm K−1 mol−1**
0.082057338(47)	L atm K−1 mol−1
82.057338(47)	cm3 atm K−1 mol−1

Standard reference conditions in current use

STP - Standard Temperature and Pressure

STP is commonly used to define standard conditions for temperature and pressure which is important for the measurements and documentation of chemical and physical processes:

STP - Standard Temperature and Pressure - is defined by IUPAC (International Union of Pure and Applied Chemistry) as air at 0^oC (273.15 K, 32 ^oF) and 10^5 pascals (1 bar).

The earlier (until 1982) IUAPC definition of STP to *273.15 K* and *1 atm (1.01325 10^5 Pa)* is discontinued. However,

- These conditions are still the most commonly used to define the volume term **Nm^3** (Normal cubic meter) and in Italy they are usually named as normal conditions **(!!!)**
- At these conditions, the volume of 1 mol of a gas is 22.4136 liters.

NTP - Normal Temperature and Pressure

NTP is commonly used as a standard condition for testing and documentation for example of fan capacities:

NTP - Normal Temperature and Pressure - is defined as air at 20^oC (293.15 K, 68^oF) and 1 atm (101.325 kN/m^2, 101.325 kPa, 14.7 psia, 0 psig, 29.92 in Hg, 407 in H_2O, 760 torr). Density 1.204 kg/m^3 (0.075 pounds per cubic foot)

1 Pa = 10^{-6} N/mm^2 = 10^{-5} bar = 0.1020 kp/m^2 = $1.02x10^{-4}$ m H_2O = $9.869x10^{-6}$ atm = $1.45x10^{-4}$ psi (lbf/in^2) = 0.0075006 mmHg

IUPAC. (2014). Compendium of Chemical Terminology 2nd ed. (the “Gold Book”). Blackwell Scientific Publications, Oxford, 1670. https://doi.org/10.1351/goldbook.I03352

Gas Density

$$\rho = \frac{\text{mass}}{\text{volume}} \; [=] \; \frac{g}{l}$$

$$\rho = \frac{\text{molecular weight}}{\text{molar volume}} \; [=] \; \frac{g \cdot mole^{-1}}{l \cdot mole^{-1}}$$

← - - - → Avogadro's rule

Density → dependent on ***temperature***

T grows → gas *expands* → *same mass* holds ***higher volume*** → ***density decreases***

Standard conditions (0°C, 1 atm)

$$\rho = \frac{MW}{22{,}4} \; [=] \; g \cdot l_n^{-1} \; [=] \; kg \cdot m_n^{-3}$$

MW in $g \cdot mole^{-1}$

Gas	MW ($g\ mole^{-1}$)	ρ ($g\ l_n^{-1}$, $kg\ m_n^{-3}$)
H_2	2	0,089
He	4	0,179
N_2	28	1,25
O_2	32	1,43
Air	28,62	1,278

Units

ppm | g/m³ mg/m³ µg/m³

$$ppm = \frac{volume\ of\ pollutant\ gas}{total\ volume\ of\ gas\ mixture} * 10^6$$

$$C_{mass} = \frac{M_P}{V_t} = \frac{C_{ppm} * MW_P}{R * T/P}$$

$$M_P = n_P * MW_P$$

$$V_t = \frac{n * R * T}{P}$$

C_{mass}= mass concentration, µg/m^3

C_{ppm}= volume or molar concentration, ppm

M_p= mass of pollutant gas, µg

MW_p= molecular weight of pollutant gas, g/gmol

T= temperature, K

P = preassure, Pa

R= 8.314 Pa*m^3/gmol*K

Exercise 1.2

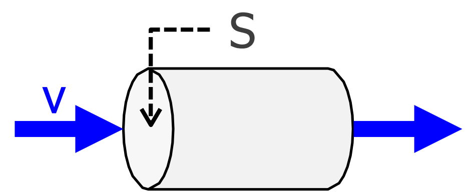
Assume that the Air Quality Standard for Ozone (MW=48) is 0.075 ppm in 8 hours and for sulfur dioxide (MW=64.06) is 0.14 ppm in 24 hours.

a) What are the AQSs for ozone and sulfur dioxide expressed in $\mu g/m^3$ at 25°C and 1 atm?

b) Assume that a sample of air at 25°C and containing SO_2 gas at a concentration equal to the AQS is raised to 150°C. What is its SO_2 concentration at 150°C in ppm and $\mu g/m^3$?

Volume flow rates Qv

- Q_V (volume/time) = v·S
  - v = gas flow velocity
  - S = duct cross section



- Gas flow rates in volume Q (volume/time) depend on T and P

$$Q = \frac{nRT}{P}, \text{ with } n = \frac{M}{MW} \text{ where } M = \text{mass flow rate, } MW = \text{molecular weight}$$

$Q_1 (T_1, P_1)$ → any variation in T and/or P → $Q_2 (T_2, P_2)$

$$Q_1 = \frac{nRT_1}{P_1}; Q_2 = \frac{nRT_2}{P_2} \longrightarrow Q_2 = Q_1 \frac{P_1 \cdot T_2}{P_2 \cdot T_1}$$

Conservation of the mass: the number of moles remains the same

- Actual gas T and P conditions usually different from reference conditions (N and/or STP) adopted in emission limits definition

Exercise 1.3. Volume flow rates conversion

Convert a flow rate Q of 10 Nm^3/h at STP conditions of 0 °C, 1 atm (earlier IUAPC definition) to actual stack gas conditions (180°C, 0.9 atm)

$$Q = \frac{nR\mathbf{T}}{\mathbf{P}} \Rightarrow Q_a = \frac{nR\mathbf{T}_a}{\mathbf{P}_a},\ Q_n = \frac{nR\mathbf{T}_n}{\mathbf{P}_n}$$

Mass concentration conversion

Mass concentrations of gases C (mass/volume) depend on T and P

$$C = \frac{M}{V} = \frac{MP}{nRT}$$

$C_1 (T_1, P_1)$ → any variation in T and/or P → $C_2 (T_2, P_2)$

$$C_1 = \frac{M}{V_1} \; ; \; C_2 = \frac{M}{V_2} \longrightarrow C_2 = C_1 \frac{V_1}{V_2} = C_1 \frac{P_2 \cdot T_1}{P_1 \cdot T_2}$$

Actual gas T and P conditions usually different from reference conditions (NTP/or STP) adopted in emission limits definition

Exercise 1.4. Mass concentration conversion

Convert a concentration C of 20 mg/m^3 from actual conditions (100 °C, 1 atm) to STP (earlier IUAPC definition) reference conditions (0°C, 1 atm)

Mass concentrations and volume flow rates conversion: reference conditions

Emission limits established in terms of reference conditions for T, P, moisture and oxygen content

- moisture: dry basis
- oxygen: % vol

Conversion for moisture

$$C_{db} = \frac{C_a}{(1 - U/100)} \qquad Q_{v,db} = Q_{v,a} \cdot (1 - U/100)$$

C_{db}, Q_{db} = mass concentration and volume flow rate on dry basis;
C_a, Q_a = mass concentration and volume flow rate at actual conditions;
U = gas moisture content (% volume)

Conversion for oxygen

$$C_{O_2\,ref} = C_{O_2\,a} \frac{21 - O_{2\,ref}}{21 - O_{2\,a}} \qquad Q_{v,\,O_2\,ref} = Q_{v,\,O_2 a} \cdot \frac{21 - O_{2a}}{21 - O_{2\,ref}}$$

$C_{O2\,ref}$, $Q_{v,O2\,ref}$ = mass concentration and volume flow rate at O_2 reference conditions;
$C_{O2\,a}$, $Q_{v,O2\,a}$ = mass concentration and volume flow rate at O_2 actual conditions;
$O_{2\,a}$, $O_{2\,ref}$ = oxygen concentrations at actual and reference conditions (% volume)

Exercise 1.5. Mass concentrations and volume flow rates conversion: reference conditions

$Q_{v,a}$ = 5 m^3_a/h, CO = 10 mg/m^3_a, U = 15% by volume. Calculate:

a) CO concentration on dry volume basis;

b) $Q_{v,db}$;

c) CO mass flow rate

Exercise 1.6. Mass concentrations and volume flow rates conversion: reference conditions

Natural gas fuelled turbine:
$Q_{v,db}$ = 45,000 $m^3{}_n$/h, NO_x = 400 mg/$m^3{}_{n,db}$, $O_{2,a\ db}$= 13%. Calculate:

a) NO_x concentration at $O_{2\ ref}$ = 15%;

b) $Q_{v,O2\ ref}$;

c) NO_x mass flow rate M

Exercise 1.7. Mass concentrations and volume flow rates conversion: reference conditions (3)

A sample stream of dry gas is being withdrawn from a stack. The stack gases are at **200°C** and **730 mm Hg**. The stream flows through a heated filter, a set of cooled impingers, a small air pump and then through a flow meter (see figure of particulate sampling apparatus).

The rate of flow is determined to be 30.0 liters/minute at 20°C and 790 mm Hg.

a) Calculate the actual volumetric flow rate through the filter (at 200°C and P=730 mm Hg)

b) If 1.42 mg of solid particles are collected on the filter in 30 minutes, calculate the concentration of particles in the stack gas (in µg/m3)