University of Mosul

College of Petroleum & Mining Engineering

Petroleum Pollution

Lecture …(1)….

Petroleum and Refining Engineering Department

Table 2.1 Air Emissions From Exploration, Development, and Production of Petroleum (E&P Forum, 1993; Bashat, 2003)

Main Sources	Environmentally Significant Components	Type of Operation
Vent gases Flare gases Blowdown from bulk chemicals	NO_x, SO_x, H_2S, CO_x, VOC, hydrocarbons such as CH_4, carbon, particulates, PAHs, benzene, toluene, ethylbenzene, and ortho-, meta-, and para-xylene (BTEX)	Drilling Production
Engine exhausts	NO_x, SO_x, CO_x, VOC, PAHs, formaldehyde, carbon particulates	Seismic Construction and commissioning Drilling Production Maintenance Abandonment
Fugitive gases	VOC, BTEX	Construction and commissioning Drilling Production Maintenance

Table 5.1 Maximum Effluent Level From the Petroleum Industry (World Bank Group, 1998)

Parameter	Maximum Value
Nitrogen oxides (mg/m^3) (excludes NO_x emissions from catalytic units)	460
Sulfur oxides (mg/m^3)	150 for SRUs and 500 for other units.
PM (mg/m^3)	50
Nickel and vanadium (combined) (mg/m^3)	2
Hydrogen sulfide (mg/m^3)	152

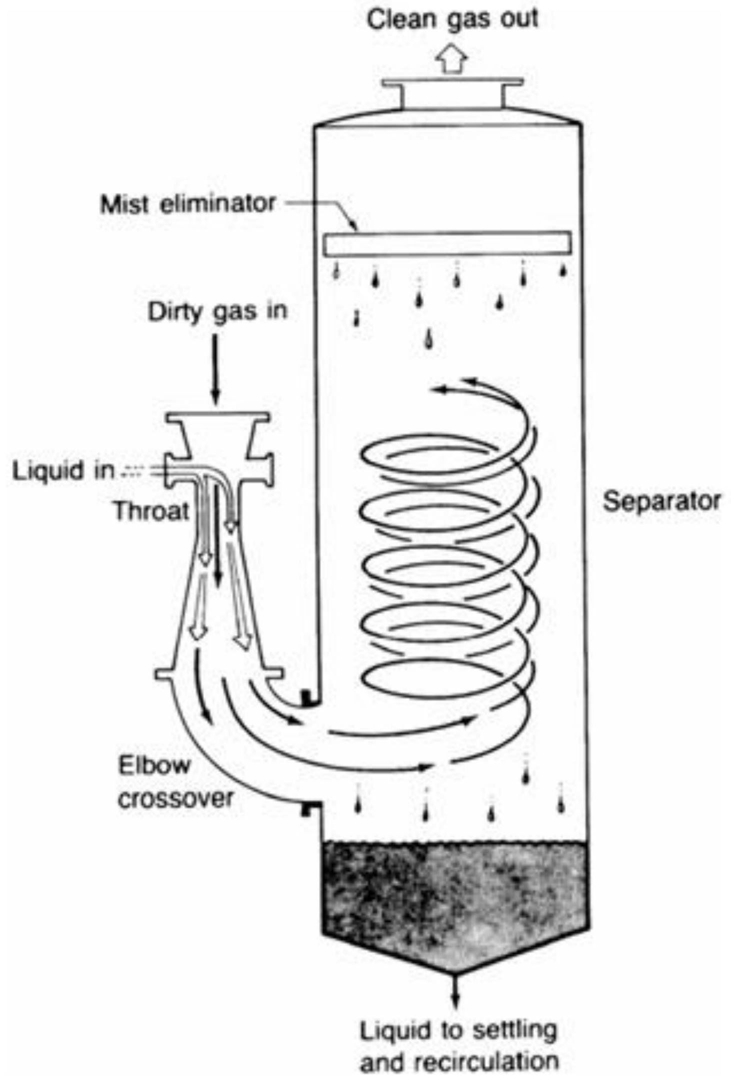

Figure 5.13 Venturi scrubber with cyclone separator and mist eliminator (A&WMA, 2007).

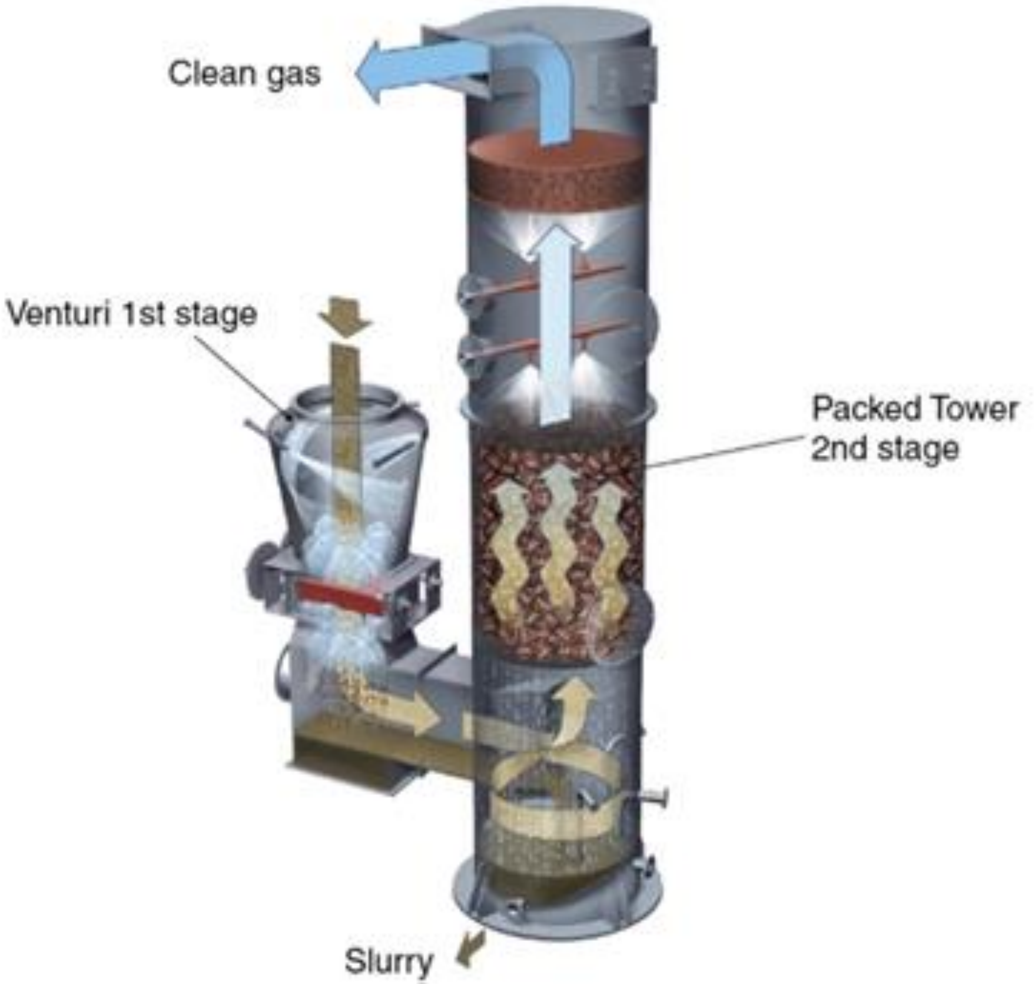

Figure 5.14 Two-stage wet scrubber design including a venturi scrubber with a packed-bed section (MikroPul, 2015).

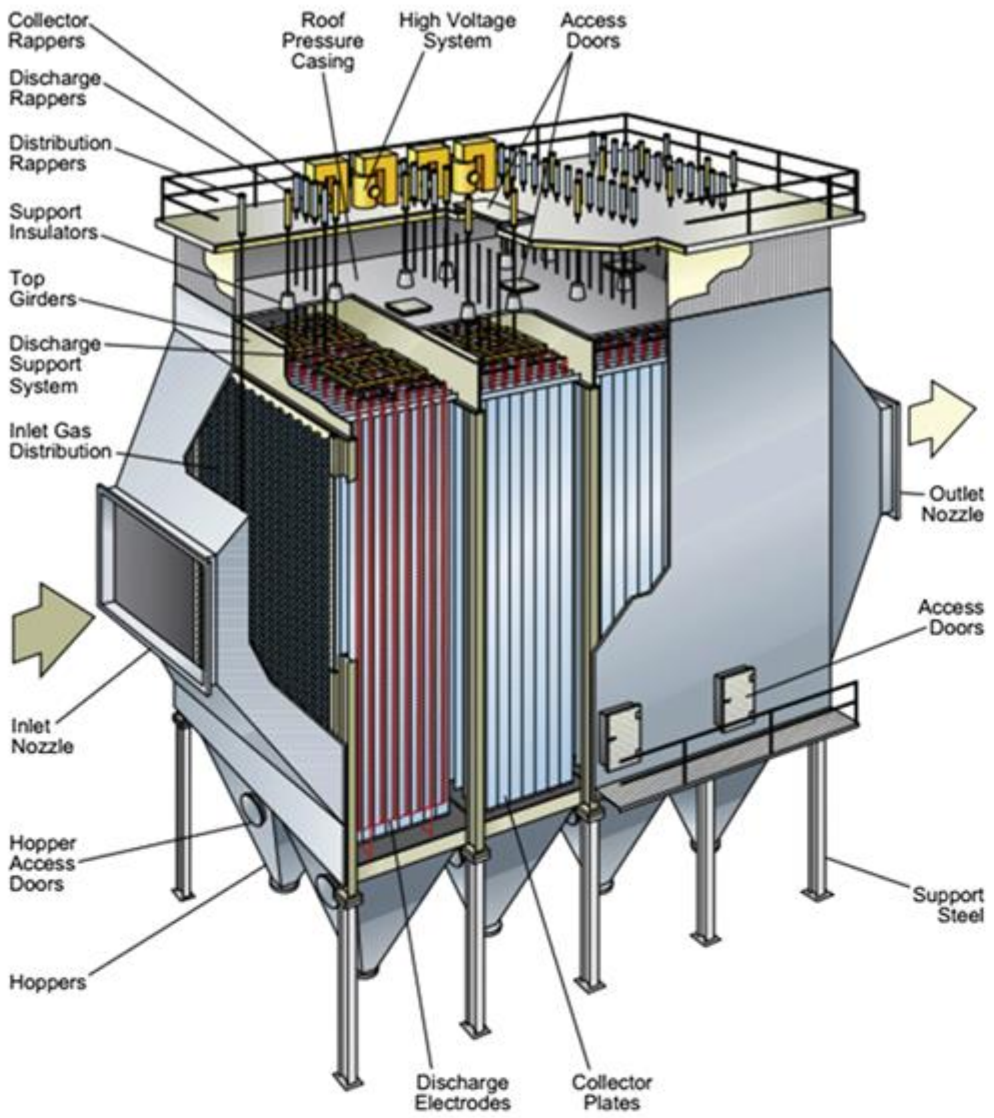

Figure 5.15 Schematic of an electrostatic precipitator (Courtesy of The Babcock & Wilcox Company).

Example 5.1

In an ESP, assume that the gas-flow rate, the particle diameter, the electric field, the particle charge, the viscosity, the temperature, and the pressure are 35 m^3/s, 0.5 μm, 60,000 V/m, 1.6×10^{-18} C, 1.81×10^{-5} kg/ms, 293 K, and 10,1300 Pa, respectively. Also suppose that each plate has the dimensions 5 m by 3 m and the collection efficiency of the ESP must be 99%. What is the required number of plates?

Solution: The mean-free path of the gas molecules can be calculated using Eq. (5.17):

$$\lambda = 6.61 \times 10^{-8}\left(\frac{293}{293}\right)\left(\frac{101,300}{101,300}\right) = 6.61 \times 10^{-8}\ (\mathrm{m})$$

The Cunningham correction factor can be obtained from Eq. (5.16):

$$C_m = 1 + 2.54\left(\frac{6.61 \times 10^{-8}}{5 \times 10^{-7}}\right) + 0.8\left(\frac{6.61 \times 10^{-8}}{5 \times 10^{-7}}\right)\exp\left(\frac{-0.55 \times 5 \times 10^{-7}}{6.61 \times 10^{-8}}\right)$$
$$= 1.333$$

The migration velocity is calculated using Eq. (5.15):

$$w_e = \frac{1.6 \times 10^{-18} \times 60,000 \times 1.333}{3\pi \times 1.81 \times 10^{-5} \times 5 \times 10^{-7}} = 1.5 \times 10^{-3}\ (\mathrm{m/s})$$

According to Eq. (5.14), for an efficiency of 99%, the area of the collecting electrodes is 107,453.97 m^2, which was obtained as follows:

$$0.99 = 1 - \exp\left(\frac{-0.0015A}{35}\right)$$

Since a single plate gives a collecting area of $2 \times 5 \times 3 = 30\ m^2$ (counting both sides) and based on this fact each of the two terminal plates offers only a single collecting side, it is necessary to add 1 to the number of plates; thus the required number of plates can be obtained as follows:

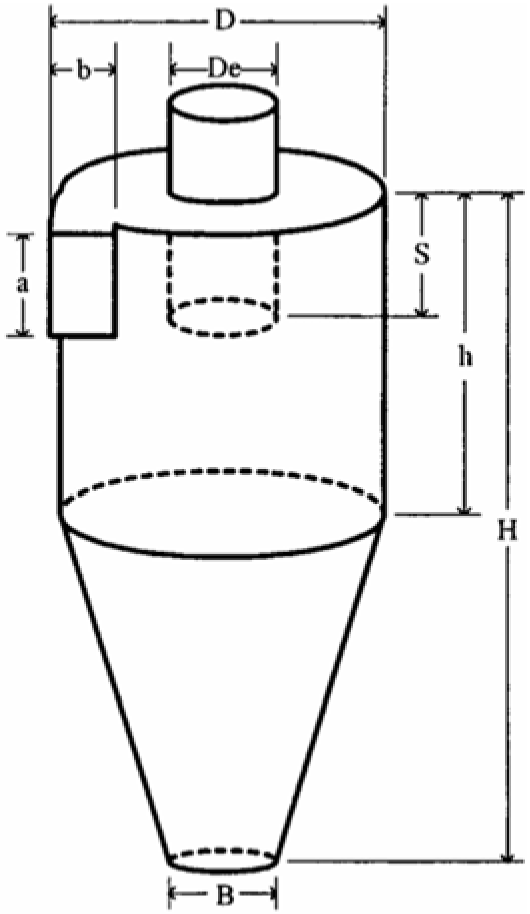

Figure 5.16 Typical tangential inlet cyclone (Kuo and Tsai, 2001).

Table 5.2 Some of the Available Equations for Theoretical Collection Efficiency and Cutoff Diameter of the Cyclone (Dirgo and Leith, 1985; Kuo and Tsai, 2001)

Theory	Equation for the Theoretical Collection Efficiency	Equation for the Cutoff Diameter	Parameters
Lapple	$d_{p_{50}} = \sqrt{\frac{9\mu b}{2\pi \rho_p v_i C N_t}}$		$d_{p_{50}}$, The cutoff diameter (m); d_p, particle diameter (m); μ, gas viscosity (Pa s); b, cyclone inlet width (m); ρ_p, particle density (kg/m^3); v_i, gas inlet velocity (m/s); C, slip-correction factor of the particle corresponding to $d_{p_{50}}$; $N_t = t v_i/\pi$; D, number of turns; and t, residence time that equals to the volume of the cyclone divided by the volumetric flow rate (Q).
Theodore and DePaola	$\eta = \frac{1}{1 + (d_{p_{50}}/d_p)^2}$	$d_{p_{50}} = \sqrt{\frac{9\mu b}{2\pi \rho_p v_i C N_t}}$	
Stairmand		$d_{p_{50}} = \sqrt{\frac{9\mu Q}{\pi \rho_p v_{t\max} C (H - S)}}$	$v_{t\max}$, maximum tangential velocity; H, total height of cyclone; and S, length of vortex finder or outlet duct length.
Barth	$\eta = \frac{1}{1 + \left(\frac{\pi h^* v_t^2 \rho_p d_p^2}{9\mu Q}\right)^{-3.2}}$	$d_{p_{50}} = \sqrt{\frac{9\mu Q}{\pi \rho_p v_{t\max} C (H - S)}}$	v_t, tangential gas velocity at the edge of the central core; and h^*, height of the central core.
Leith and Licht	$\eta = 1 - \exp\left[-2(C_g \psi)^{\frac{1}{2n+2}}\right]$		C_g, dimension factor of a cyclone; $\psi = C \rho_p d_p^2 v_i / 18\mu D$, impaction parameter; and n, vortex exponent.
Dietz	$\eta = 1 - \left[K_0 - \sqrt{(K_1^2 + K_2)}\right] \times \exp\left[\frac{-\pi \rho_p d_p^2 v_i (2S - a)}{18\mu ab}\right]$		The subscripted K terms are functions of particle and gas properties as well as cyclone dimensions.
Li and Wang	$\eta = 1 - \exp\left[\frac{-2\pi\lambda(S + L)}{a}\right]$		λ, a characteristic value; and $L = 2.3 D_e \sqrt[3]{\frac{D^2}{ab}}$, The natural length of cyclone.
Iozia and Leith	$\eta = \frac{1}{1 + (d_{p_{50}}/d_p)^\beta}$	$d_{p_{50}} = \sqrt{\frac{9\mu Q}{\pi \rho_p v_{t\max} \chi_c}}$	$v_{t\max} = 6.1 v_i \left(\frac{ab}{D^2}\right)^{0.61} \left(\frac{D_e}{D}\right)^{-0.74} \left(\frac{H}{D}\right)^{-0.33}$, The maximum tangential velocity; χ_c, length of the central core; and β can be calculated from $\ln \beta = 0.62 - 0.87 \ln(d_{p_{50}}) + 521 \times \ln\left(\frac{ab}{D^2}\right) + 1.05 \left[\ln\left(\frac{ab}{D^2}\right)\right]^2$.