University of Mosul

College of Petroleum & Mining Engineering

Petroleum Pollution

Lecture …(2)….

Petroleum and Refining Engineering Department

Table 2.4 **Equipment Leak Rate for Petroleum Industry (Refinery, Marketing Terminals, and Oil and Gas Production) Equipment Components (US EPA, 1995b; RTI International, 2015)**

Equipment Type/Service	Default Zero Emission Rate (kg/h/source)	Pegged Emission Rate (kg/h/source)		Correlation Equation (kg/h/source)
		10,000 ppmv	100,000 ppmv	
Valves/all	7.8×10^{-6}	0.064	0.140	$2.29 \times 10^{-6}C^{0.746}$
Pump seals/all	2.4×10^{-5}	0.074	0.160	$5.03 \times 10^{-5}C^{0.610}$
Others/all	4.0×10^{-6}	0.073	0.110	$1.36 \times 10^{-5}C^{0.589}$
Connectors/all	7.5×10^{-6}	0.028	0.030	$1.53 \times 10^{-6}C^{0.735}$
Flanges/all	3.1×10^{-7}	0.085	0.084	$4.61 \times 10^{-6}C^{0.703}$
Open-ended line/all	2.0×10^{-6}	0.030	0.079	$2.20 \times 10^{-6}C^{0.704}$

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

Table 2.7 **Main Air Emissions and Their Sources in Refineries (US EPA, 1995c, 2004; Speight, 2005; European Commission and Joint Research Center, 2013)—cont'd**

Air Emissions	Sources and/or Processes
Sulfur oxides (SO_x)	Process furnaces and boilers, fluidized catalytic cracking regenerators, CO boilers, sulfur recovery units, flare systems, incinerators, or in processes such as crude-oil desalting, atmospheric distillation, vacuum distillation, thermal cracking/visbreaking, coking, catalytic cracking, catalytic hydrocracking, hydrotreating/hydroprocessing, alkylation, isomerization, catalytic reforming, and propane deasphalting
Volatile organic compounds (VOCs)	Storage and handling facilities, as separation units, oil/water separation systems, fugitive emissions (valves, flanges, etc.), vents, flare systems
Fugitive hydrocarbons	Crude-oil desalting, atmospheric distillation, vacuum distillation, thermal cracking/visbreaking, coking, catalytic cracking, catalytic hydrocracking, hydrotreating/hydroprocessing, alkylation, isomerization, catalytic reforming, propane deasphalting, and wastewater treatment
Catalyst dust	Catalytic hydrocracking
HCl (potentially in light ends)	Isomerization
H_2S	From caustic washing in polymerization and wastewater treatment
NH_3	Wastewater treatment
Fugitive solvents	Solvent extraction and dewaxing
Fugitive propane	Propane deasphalting

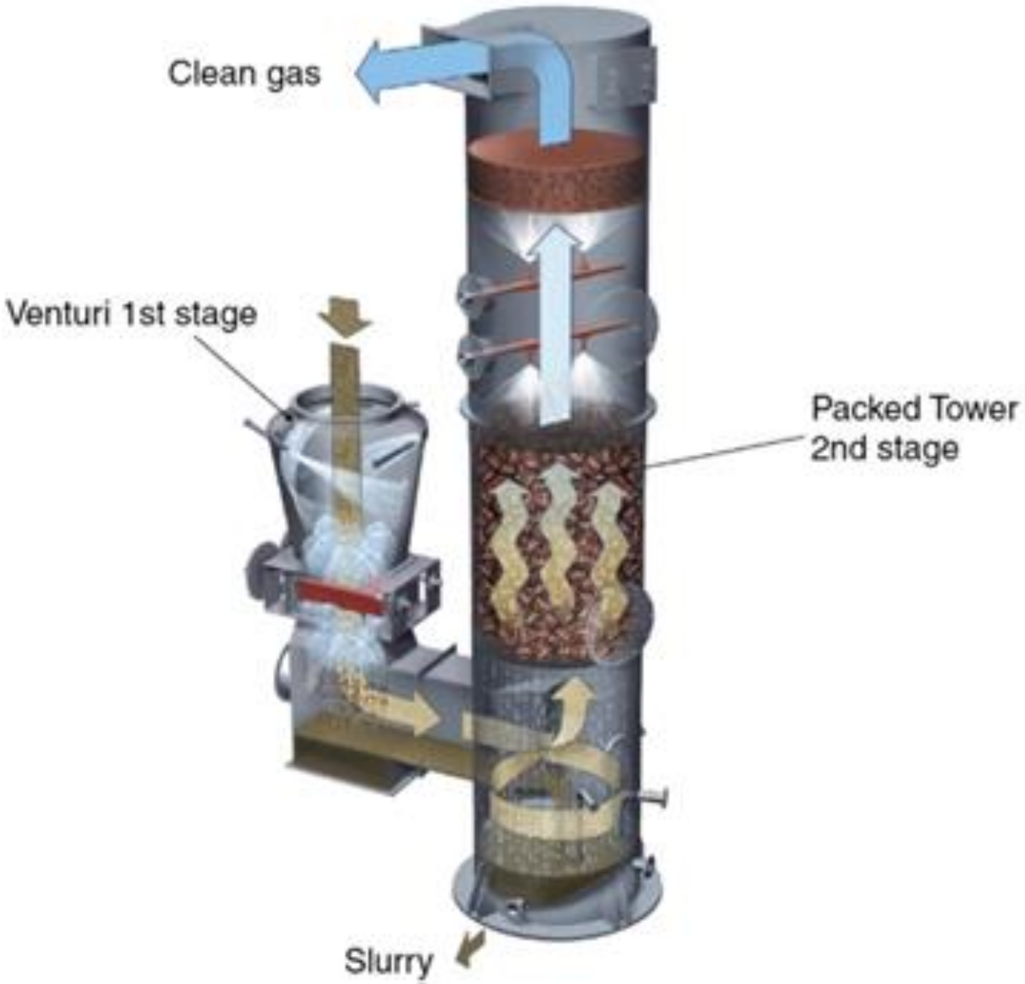

Figure 5.14 Two-stage wet scrubber design including a venturi scrubber with a packed-bed section (MikroPul, 2015).

Similar to air emissions from equipment leaks in E&P operations, mass emissions from equipment leaks in SOCMI process units and refineries can be estimated by using the average EF approach, screening ranges approach, EPA correlation approach, and unit-specific correlation approach (US EPA, 1995b; RTI International, 2015). The average EFs for SOCMI process units and refineries are presented in Table 2.9. The SOCMI average EFs estimate TOC emission rates, whereas the refinery average factors estimate nonmethane organic compound emission rates. The emission rate of TOC from all equipment can be calculated from Eq. (2.2). For refineries only, the emission factor "F_{A}" must be adjusted to account for all organic compounds in the stream because the refinery factors are only valid for nonmethane organic compounds (percents up to a maximum of 10% by weight methane are permitted). The formula is:

$$F_{\mathrm{A}} = F_{\mathrm{A}} \times \left(\frac{\mathrm{WF}_{\mathrm{TOC}}}{\mathrm{WF}_{\mathrm{TOC}} - \mathrm{WF}_{\mathrm{methane}}} \right) \tag{2.5}$$

where $\mathrm{WF}_{\mathrm{methane}}$ is the average weight fraction of methane in the stream. Thus Eq. (2.2) for refineries can be rewritten as follows (US EPA, 1995b):

$$E_{\mathrm{TOC}} = F_{\mathrm{A}} \times \left(\frac{\mathrm{WF}_{\mathrm{TOC}}}{\mathrm{WF}_{\mathrm{TOC}} - \mathrm{WF}_{\mathrm{methane}}} \right) \times \mathrm{WF}_{\mathrm{TOC}} \times N \tag{2.6}$$

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:

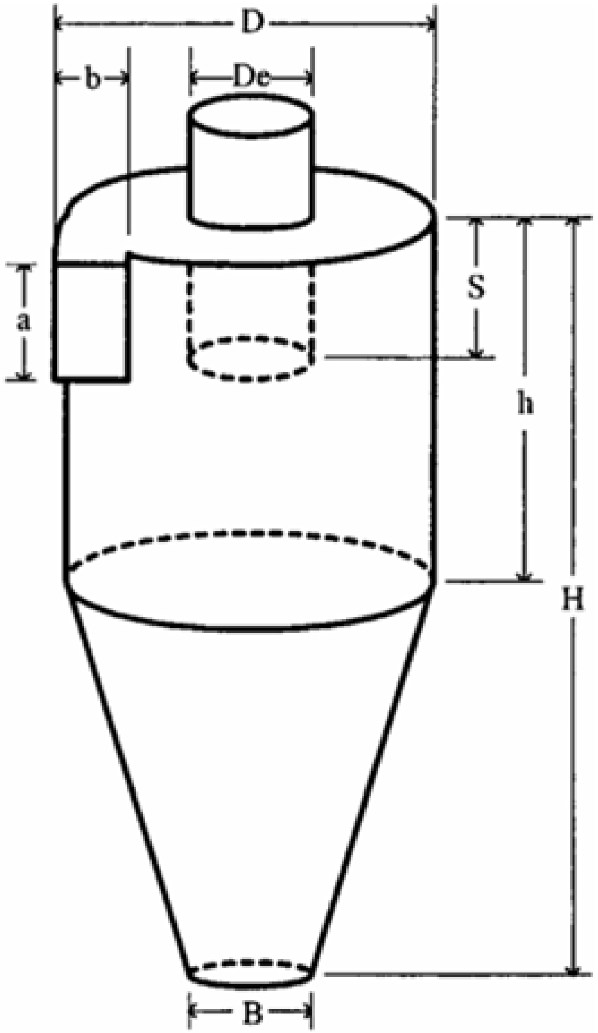

Figure 5.16 Typical tangential inlet cyclone (Kuo and Tsai, 2001).

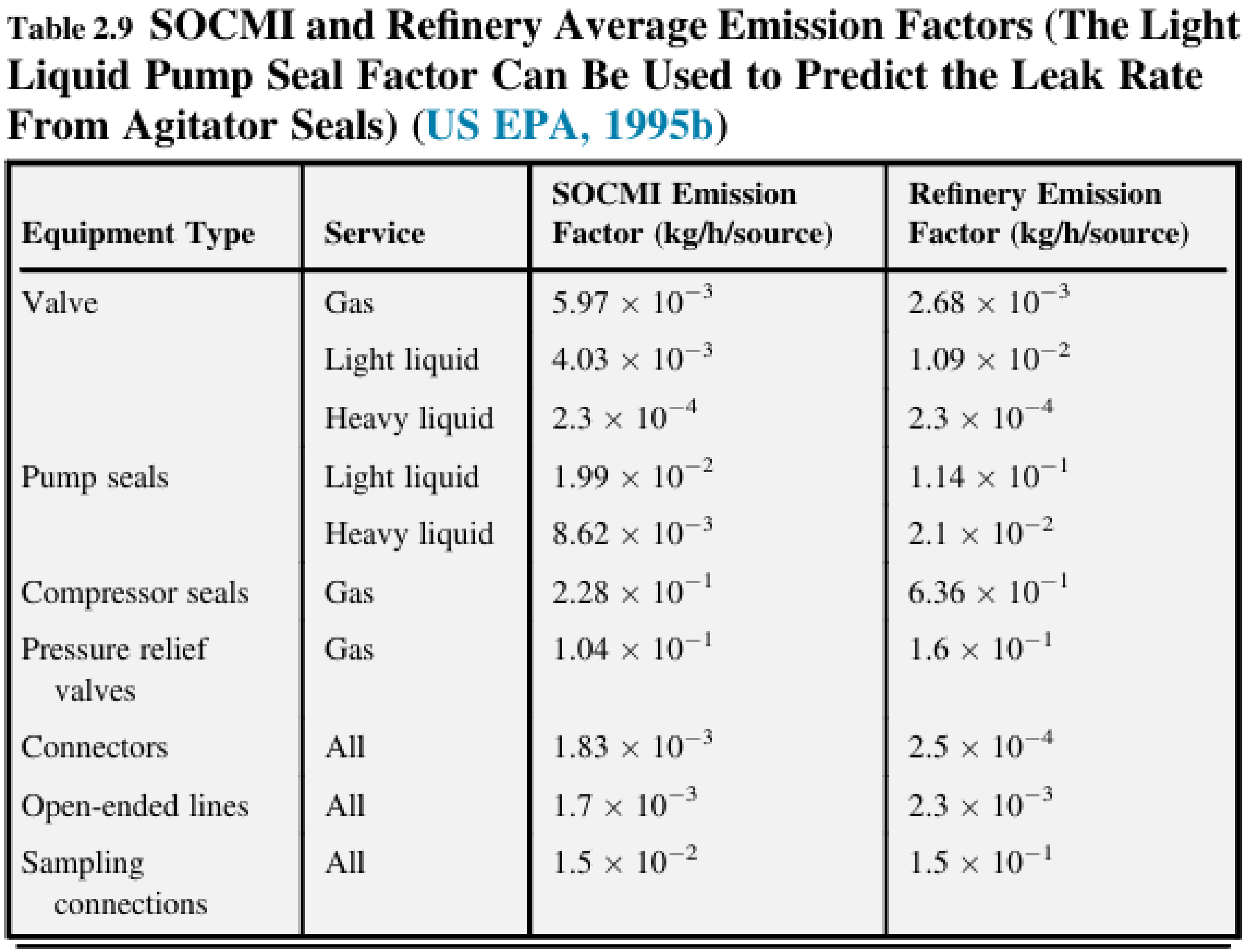

Table 2.9 **SOCMI and Refinery Average Emission Factors (The Light Liquid Pump Seal Factor Can Be Used to Predict the Leak Rate From Agitator Seals) (US EPA, 1995b)**

Equipment Type	Service	SOCMI Emission Factor (kg/h/source)	Refinery Emission Factor (kg/h/source)
Valve	Gas	5.97×10^{-3}	2.68×10^{-3}
	Light liquid	4.03×10^{-3}	1.09×10^{-2}
	Heavy liquid	2.3×10^{-4}	2.3×10^{-4}
Pump seals	Light liquid	1.99×10^{-2}	1.14×10^{-1}
	Heavy liquid	8.62×10^{-3}	2.1×10^{-2}
Compressor seals	Gas	2.28×10^{-1}	6.36×10^{-1}
Pressure relief valves	Gas	1.04×10^{-1}	1.6×10^{-1}
Connectors	All	1.83×10^{-3}	2.5×10^{-4}
Open-ended lines	All	1.7×10^{-3}	2.3×10^{-3}
Sampling connections	All	1.5×10^{-2}	1.5×10^{-1}

Tables 2.10 and 2.11, respectively. To calculate TOC emissions using the screening ranges approach, Eq. (2.4) can be used. For refineries only, the emission factors "F_{G}" and "F_{L}" must be adjusted to account for all organic compounds in the stream because the refinery factors are only valid for nonmethane organic compounds. The equations are:

$$F_{\mathrm{G}} = F_{\mathrm{G}} \times \left(\frac{\mathrm{WF_{TOC}}}{\mathrm{WF_{TOC}} - \mathrm{WF_{methane}}} \right) \tag{2.7}$$

$$F_{\mathrm{L}} = F_{\mathrm{L}} \times \left(\frac{\mathrm{WF_{TOC}}}{\mathrm{WF_{TOC}} - \mathrm{WF_{methane}}} \right) \tag{2.8}$$

Thus Eq. (2.4) for refineries can be rewritten as follows (US EPA, 1995b):

$$\begin{aligned} E_{\mathrm{TOC}} = & \left(\left[F_{\mathrm{G}} \times \left(\frac{\mathrm{WF_{TOC}}}{\mathrm{WF_{TOC}} - \mathrm{WF_{methane}}} \right) \times N_{\mathrm{G}} \right] \right. \\ & \left. + \left[F_{\mathrm{L}} \times \left(\frac{\mathrm{WF_{TOC}}}{\mathrm{WF_{TOC}} - \mathrm{WF_{methane}}} \right) \right] \right) \end{aligned} \tag{2.9}$$