Problems

7.1 A vertical countercurrent spray chamber has a 2.0m contact zone and operates with a liquid/gas ratio of 1.0 L/m^3 and an average droplet diameter of 200 microns. During a test run, the following data were taken on the unit:

average scrubber temperature = 25°C

gas velocity 0.4 m/s

inlet loading $3.5g/m^3$

The following particle size distribution was obtained from a cascade impactor.

Size Range, μm	< 4	$4-8$	$8-16$	$16-30$	$30-50$	> 50
Mass, mg	25	125	100	80	20	10

Estimate the overall efficiency of the unit, assuming 20% spray utilization.

solution

From Table B. 2 in Appendix B, $\mu_g = 0.0447\, \text{lb}_\text{m}/\text{hr}\cdot\text{ft} = 1.85\times10^{-5} P_a\cdot s$, $\rho_{air} = 1.183$ kg/m^3.

the settling velocity of an 2μm particle(Assuming Stokes regime flow), Assuming $\rho_p = 1000\ g/m^3$.

$$V_p = \frac{\rho_p d_{pi}^2}{18\mu} g = \frac{1000\times(2\times10^{-6})^2}{18\times1.85\times10^{-5}}\times9.81 = 1.178\times10^{-4}\, m/s$$

the settling velocity of an 200μm droplets(Assuming Transition regime flow) ,

$$V_d = \frac{0.153 d_p^{1.14}\rho_p^{0.71}g^{0.71}}{\mu^{0.43}\rho^{0.29}} = \frac{0.153\times(200\times10^{-6})^{1.14}\times(1000\times9.81)^{0.71}}{(1.85\times10^{-5})^{0.43}\times1.183^{0.29}} = 0.654\, m/s$$

Check $Re_d = \frac{200\times10^{-6}\times1.183\times0.654}{1.85\times10^{-5}} = 8.36$ $\quad 2 \le Re_d \le 500$ **OK**

$$stk_i = \frac{C\rho_p d_{pi}^2 (V_d - V_p)}{9\mu_g D} = \frac{1000\times(2\times10^{-6})^2\times(0.654-0.0001178)}{9\times1.85\times10^{-5}\times200\times10^{-6}} = 0.079$$

$$\eta_{Ti} = (\frac{stk_i}{stk_i+0.7})^2 = \left(\frac{0.079}{0.079+0.7}\right)^2 = 0.010$$

$$\eta_i = 1 - exp(-\frac{3}{2}\frac{Q_l}{Q_g}\cdot\frac{H}{D}\cdot\frac{V_d - V_p}{V_d - V_g}\cdot\eta_{Ti})$$

$$= 1 - \exp(-\frac{3}{2}\times0.001\times20\%\times\frac{2}{200\times10^{-6}}\times\frac{0.654}{0.654-0.4}\times0.010)$$

$$= 0.076$$

And so on for the rest

Size Range, μm	$\bar{d}_{pi}, \mu m$	stk_i	η_{Ti}	η_i	$m_i, \%$	$\eta_i m_i, \%$
< 4	2.0	0.079	0.010	0.076	6.94	0.5
$4-8$	6.0	0.706	0.252	0.857	34.72	29.7
$8-16$	12.0	2.812	0.641	0.993	27.78	27.6
$16-30$	24.0	10.15	0.875	0.999	22.22	22.2
$30-50$	40.0	29.182	0.954	0.999	5.56	5.5
> 50	50	43.607	0.969	0.999	2.78	2.8

$$\eta_T = \sum_{i=1}^{6} \eta_i m_i = 88.4\%$$

7.2 Determine the overall removal efficiency of a venturi scrubber for the particle distribution given below. Operating parameters are $V_g = 90\text{m/s}, Q_L/Q_G = 1.5\text{L/m}^3$, and $f = 0.5$. The operating temperature is $20°\text{C}$.

Size Range, μm	$0-2$	$2-4$	$4-8$	$8-10$	$10-20$	> 20
Mass %	15	30	37	6	10	2

solution

At $20°\text{C}, \sigma = 7.2 \times 10^{-2}$ N/m and $\mu_L = 0.001$ Pa·s. Therefore,

$$D = \frac{586 \times 10^3}{V_g} (\frac{\sigma}{\rho_l})^{0.5} + 1682(\frac{\mu_l}{\sqrt{\sigma \rho_l}})^{0.45} L^{1.5}$$

$$= \frac{586000}{90} \times \left(\frac{7.2 \times 10^{-2}}{1000}\right)^{0.5} + 1682\left(\frac{0.001}{\sqrt{7.2 \times 10^{-2} \times 1000}}\right)^{0.45} \times 1.5^{1.5}$$

$$= 55.25 + 52.73 = 108.0\mu m$$

For dp=1um

$$stk_i = \frac{\rho_{pi} d_{pi}^2 V_T}{9\mu_g D} = \frac{1000 \times (1 \times 10^{-6})^2 \times 90}{9 \times 1.8 \times 10^{-5} \times 108.0 \times 10^{-6}} = 5.14$$

$$F(stk_i, f) = \frac{1}{stk_i}\left[-0.7 - stk_i f + 1.4 \ln\left(\frac{stk_i f + 0.7}{0.7}\right) + \frac{0.49}{0.7 + stk_i f}\right] = -0.187$$

$$\eta_i = 1 - exp\left[\frac{2}{55} \frac{Q_l}{Q_g} \frac{D\rho_l}{\mu_g} V_T F(stk_i, f)\right]$$

$$= 1 - exp\left[\frac{2}{55} \times 0.0015 \times \frac{108.0 \times 10^{-6} \times 1000}{1.8 \times 10^{-5}} \times 90 \times (-0.187)\right]$$

$$\approx 0.9959$$

And so on for the rest

Size Range, μm	$\bar{d}_{pi}, \mu m$	stk_i	$F(stk_i, f)$	η_i	$m_i, \%$	$\eta_i m_i, \%$
$0 - 2$	1.0	5.145	-0.1873	0.996	15	0.1494
$2 - 4$	3.0	46.305	-0.4080	1.000	30	0.3
$4 - 8$	6.0	185.221	-0.4668	1.000	37	0.37
$8 - 10$	9.0	416.747	-0.4825	1.000	6	0.06
$10 - 20$	15.0	1157.63	-0.4925	1.000	10	0.10
> 20	20	2058.009	-0.4954	1.000	2	0.02

$$\eta_T = \sum_{i=1}^{6} \eta_i m_i = 99.94\%$$