28

ENVIRONMENTAL MANAGEMENT

28.1 INTRODUCTION

In the past four decades, there has been an increased awareness of a wide range of environmental issues covering all resources: air, land, and water. More and more people are becoming aware of these environmental concerns, and it is important that professional people, many of whom do not possess an understanding of environmental problems, have the proper information available when involved with environmental issues. All professionals should have a basic understanding of the technical and scientific terms related to these issues. In addition to serving the needs of the professional, this chapter examines how one can increase his or her awareness of and help solve the environmental problems facing both industry and society.

Chapter 28 is titled Environmental Management; it provides a broad discussion of environmental issues facing today's engineers and presents some of the more recent technology to deal with the issues at hand. Some of the topics covered in this chapter include air pollution, water pollution, solid waste, etc., and several Illustrative Examples dealing with these topics are presented.

This chapter is not intended to be all-encompassing. Rather, it is to be used as a starting point. Little is presented on environmental regulations because of the enormity of the subject matter; in a very real sense, it is a moving target that is beyond the scope of this text. Further, the material primarily keys on traditional environmental topics. Although much of the material is qualitative in nature, some quantitative material and calculations are presented in the Illustrative Examples that are presented in the last section.

28.2   ENVIRONMENTAL MANAGEMENT HISTORY

BANG! The Big Bang. In 1948, physicist G. Gamow proposed the big bang theory of the origin of the universe. He believed that the universe was created in a gigantic explosion as all mass and energy were created in an instant of time. Estimates on the age of the universe at the present time range between 7 and 20 billion years, and with 13.5 billion years often mentioned as the age of the planet Earth.

The bang occurred in a split second and within a minute the universe was approximately a trillion miles wide and expanding at an unbelievable rate. Several minutes later all the matter known to humanity had been produced. The universe as it is known today was in place. Environmental problems, as they would later relate to living organisms and humans, were born.

Flash forward to the present. More than any other time in history, the 21st century will be a turning point for human civilization. Human beings may be facing ecological disasters that could affect their ability to survive. These crises could force them to reexamine the value system that has governed their lives for the past two million years (approximately) of existence.

28.2.1   Recent Environmental History

The year 1970 was a cornerstone year for modern environmental policy. The National Environmental Policy Act (NEPA), enacted on January 1, 1970, was considered a "political anomaly" by some. NEPA was not based on specific legislation; instead it referred in a general manner to environmental and quality-of-life concerns. The Council for Environmental Quality (CEQ), established by NEPA, was one of the councils mandated to implement legislation. April 22, 1970 brought Earth Day, where thousands of demonstrators gathered all around the nation. NEPA and Earth Day were the beginning of a long, seemingly never-ending debate over environmental issues.

The Nixon Administration became preoccupied with not only trying to pass more extensive environmental legislation, but also with implementing the laws. Nixon's White House Commission on Executive Reorganization proposed in the Reorganizational Plan #3 of 1970 that a single, independent agency be established, separate from the CEQ. The plan was sent to Congress by President Nixon on July 9, 1970, and this new U.S. Environmental Protection Agency (EPA) began operation on December 2, 1970. The EPA was officially born.

The aforementioned EPA works with the states and local governments to develop and implement comprehensive environmental programs. Federal laws such as the Clean Air Act, the Safe Drinking Water Act, the Resource Conservation and Recovery Act, the Comprehensive Environmental Response, Compensation, and Liability Act, etc., all mandate involvement by state and local government in the details of implementation. These laws, in a very real sense, have dictated the environmental management policies and procedures that are presently in place and serve as the subject matter for this chapter.

A waste management timetable that provides information on environmental approaches since World War II is provided in Table 28.1.

Table 28.1   Waste management timetable

Timeframe	Control
Prior to 1945	No control
1945–1960	Little control
1960–1970	Some control
1970–1975	Greater control (EPA founded)
1975–1980	More sophisticated control
1980–1985	Beginning of waste reduction management
1985–1990	Waste reduction management
1990–1995	Pollution Prevention Act
1995–2000	Sophisticated pollution prevention approaches
2000–2010	Green chemistry and engineering; Sustainability
2010–	?????

28.3 ENVIRONMENTAL MANAGEMENT TOPICS

There are two dozen topics that the authors consider to be integral parts of environmental management (there are, of course, more). Reviewing each subject area in any detail is beyond the scope of this text; the reader is referred to a key reference in the literature[1] for an extensive review of the entire field of environmental management. Additional and more specific references for each of the topics referred to above are provided below:

1. Air pollution control equipment, etc.[2–4]
2. Atmospheric dispersion modeling.[5]
3. Indoor air quality.[6]
4. Industrial wastewater management.[6,7]
5. Wastewater treatment technologies.[6,7]
6. Wastewater treatment processes.[5–7]
7. Solid waste management.[5–8]
8. Superfund.[5,6,8]
9. Municipal solid waste management.[5,6,8]
10. Hospital waste management.[5,6,8]
11. Nuclear waste management.[5,6]
12. Pollution prevention.[9–15]
13. Multimedia analysis and lifecycle cost analysis.[6,7]
14. Noise.[5,6,16,17]

15. ISO14000[5,6,18,19]
16. Environmental justice.[5,6,20–22]
17. Electromagnetic field.[5,6]
18. Acid rain.[5,6]
19. Greenhouse effect and global warning.[5,6]
20. Public perception of risk.[5,6,20–22]
21. Health risk assessment.[5–7,23]
22. Hazard risk assessment.[5–7,24]
23. Risk communication.[5,6,20–22]
24. Environmental implication of nanotechnology.[25,26]

28.4 APPLICATIONS

Much of the material to follow has been drawn from the literature.[1,7,26] The Illustrative Examples in this section were extracted from numerous sources including problem workbooks prepared under National Science Foundation grants.[9,10,26,27]

Illustrative Example 28.1 Highlight the difference between a wastewater "direct discharger" and an "indirect discharger."

Solution   A direct discharger is an industrial plant that discharges its effluent wastewater directly to a surrounding water source with no intermediate means of treatment. An indirect discharger is a plant that first discharges to a publicly owned treatment works (POTW) facility prior to release to the environment.

Illustrative Example 28.2 Identify three water systems (two of which involve a flowing medium) in the order of increasing complexity that are commonly modeled for water quality analysis. What assumptions are made for each system?

Solution

1. Rivers—Can be modeled in one, two and three dimensions.
2. Lakes—Closed system. Will be subject to evaporative effects. Assumes poor mixing within the lake (temperature stratification with depth).
3. Estuaries—Complex mass balance. Boundaries must be defined. Can be defined as a steady-state condition. Assume time averaged and distance averaged conditions with respect to area, flow, and reaction rates.

Illustrative Example 28.3 PALT (Pat Abulencia and Louis Theodore) engineers have been requested to determine the minimum distance downstream from a cement dust emitting source that will be free of cement deposit. The source is equipped with a cyclone located 150 ft above ground level. They assume ambient

conditions are at 60°F and 1 atm and neglect meteorological aspects. Additional data are given below:

Particle size range of cement dust is 2.5–50 microns.
Specific gravity of the cement dust is 1.96.
Wind speed is 3.0 miles/hr.

Solution   A particle diameter of 2.5 microns is used to calculate the minimum distance downstream free of dust since the smallest particle will travel the greatest horizontal distance. In order to determine the value of K for the appropriate size of the dust, first calculate the particle density using the specific gravity given and determine the properties of the gas (assume air)

$$\rho_p = SG(62.4) = 1.96(62.4) = 122.3 \, lb/ft^3$$

$$\rho_{air} = \frac{PM}{RT} = \frac{(1)(29)}{(0.73)(60 + 460)} = 0.0764 \, lb/ft^3$$

The viscosity of air (Appendix A, Table A.3), μ, at 60°F is $1.22 \times 10^{-5} \, lb/ft \cdot s$. Calculate the value of K.

$$K = d_p \left(\frac{g\rho_p\rho_{air}}{\mu^2}\right)^{1/3} = \frac{2.5}{(25,400)(12)} \left(\frac{(32.174)(122.3)(0.0764)}{(1.22 \times 10^{-5})^2}\right)^{1/3} = 0.104$$

Stokes' law range applies since $K < 3.3$.

Use the appropriate terminal settling velocity equation and calculate the terminal settling velocity in ft/s.

$$v = \frac{gd_p^2\rho_p}{18\mu} = \frac{(32.174)[2.5/(25,400)(12)]^2(122.3)}{18(1.22 \times 10^{-5})}$$

$$= 1.21 \times 10^{-3} \, ft/s$$

Calculate the approximate time for descent in seconds.

$$t = \frac{h}{v} = \frac{150}{1.21 \times 10^{-3}}$$

$$= 1.24 \times 10^5 \, s$$

Calculate the horizontal distance traveled in miles

$$x = \frac{t}{v_{wind}} = \frac{1.24 \times 10^5}{3.0/3600}$$

$$= 103.3 \, miles$$

Illustrative Example 28.4   It is proposed to install a pulse-jet fabric filter system to clean an airstream containing particulate pollutants. You are asked to select the most appropriate filter bag fabric considering performance and cost. Pertinent design and operating data, as well as fabric information, are given below in Table 28.2.

Volumetric flowrate of polluted airstream = 10,000 scfm (60°F, 1 atm)
Operating temperature = 250°F
Concentration of pollutants = 4.00 gr/ft^3
Average ACR = 2.5 cfm/ft^2 cloth
Collection efficiency requirement = 99%

Table 28.2   Pulse-jet bag data provided by manufacturer

Filter Bag	A	B	C	D
Tensile strength	Excellent	Above average	Fair	Excellent
Recommended maximum temperature (°F)	260	275	260	220
Resistance factor	0.9	1.0	0.5	0.9
Cost per bag, ($)	26	38	10	20
Standard size	8 in × 16 ft	10 in × 16 ft	1 ft × 16 ft	1 ft × 20 ft

Note: No bag has an advantage from the standpoint of durability under the operating conditions for which the bag was designed.

Solution   Bag D is eliminated since its recommended maximum temperature (220°F) is below the operating temperature of 250°F. Bag C is also eliminated since a pulse-jet fabric filter system requires the tensile strength of the bag to be at least above average.

Consider the economics for the two remaining choices. The cost per bag is $26.00 for A and $38.00 for B. The gas flowrate and filtration velocity are

$$q = 10,000 \left(\frac{250 + 460}{60 + 460} \right)$$

$$= 13,654 \, \text{acfm}$$

$$v_f = 2.5 \, \text{cfm/ft}^2 \text{ cloth}$$

$$= 2.5 \, \text{ft/min}$$

The filtering (bag) area is then

$$S_c = q/v_f$$

$$= 13,654/2.5$$

$$= 5462 \, \text{ft}^2$$

For bag A, the area and number, N, of bags are

$$S = \pi DH$$
$$= \pi\left(\tfrac{8}{12}\right)(16)$$
$$= 33.5\,\text{ft}^2$$
$$N = S_c/S$$
$$= 5462/33.5$$
$$= 163$$

For bag B:

$$S = \pi\left(\tfrac{10}{12}\right)(16)$$
$$= 41.9\,\text{ft}^2$$
$$N = 5462/41.9$$
$$= 130$$

The total cost (TC) for each bag is as follows:

For bag A:

$$\text{TC} = N\ (\text{cost per bag})$$
$$= (163)(26.00)$$
$$= \$4238$$

For bag B:

$$\text{TC} = (130)(38.00)$$
$$= \$4940$$

Since the total cost for bag A is less than bag B, select bag A.

Illustrative Example 28.5   You are requested to determine the number of filtering bags required and cleaning frequency for a plant equipped with a fabric system. Operating and design data are given below:

Volumetric flow rate of the gas stream = 50,000 acfm
Dust concentration = 5.0 gr/ft^3
Efficiency of the fabric filter system = 98.0%
Filtration velocity = 10 ft/min
Diameter of filtering bag = 1.0 ft
Length of filtering bag = 15 ft

The system is designed to begin cleaning when the pressure drop reaches 8.0 in. H_2O. The pressure drop is given by the following empirical equation

$$\Delta P = 0.2 v_f + 5 \, c v_f^2 t$$

where ΔP is the pressure drop, in. H_2O; v_f is the filtration velocity, ft/min; c is the dust concentration, lb/ft^3; and t is the time since the bags were cleaned, min.

Solution   To calculate N, you again need the total required surface area of the bags and the surface area of each bag.
    Calculate the filtering area

$$S_c = q/v_f$$
$$= 50,000/10$$
$$= 5000 \, ft^2$$

The area per bag is

$$S = \pi D H$$
$$= (\pi)(1.0)(15)$$
$$= 47.12 \, ft^2$$

The number of bags may now be calculated

$$N = S_c/S$$
$$= 5000/47.12$$
$$= 106$$

Since $5.0 \, gr/ft^3 = 0.0007143 \, lb/ft^3$ and

$$\Delta P = 0.2 \, v_f + 5 \, c v_t^2 t,$$

Substituting

$$8.0 = (0.2)(10) + (5)(0.0007143)(10)^2 t$$

Solving for t:

$$t = 16.8 \, min$$

Illustrative Example 28.6   The primary difference between confined flow in pipes and open channel flow is that in open channel flow, the cross-sectional area of the flow is not predetermined but may be a variable that depends on other factors.
    One of the basic equations for calculating the flow rate, q (ft^3/s), as a function of depth of flow and channel characteristics is the Manning equation. It is given by:

$$q = \frac{1.486}{n} A r_h^{2/3} S^{1/2}$$

In this equation, n, is a roughness coefficient which may vary from 0.01 for smooth uniform channels to 0.03 or higher for irregular natural river channels, and S is the channel bottom slope (not the cross-sectional area). The cross-sectional area for flow is (A) and r_h is the hydraulic radius (equal to A/P), where P is the wetted perimeter of the cross-section.

Water is passing through a trapezoidal channel whose bottom base, top base (open to the atmosphere), and height are 20 ft, 50 ft, and 7.5 ft, respectively. If $S = 0.0008$ and $n = 0.02$, calculate the volumetric flow rate of the water in ft^3/s.

Solution   Calculate the cross-sectional area available for flow in the channel.

$$A = (l_{base} + l_{top})(h/2) = (20 + 50)(7.5/2) = 262.5 \, ft^2$$

Calculate the wetted perimeter of the trapezoid.

$$P = 20 + [7.5^2 + 15^2]^{1/2} = 36.8 \, ft$$

Calculate the hydraulic radius.

$$r_h = \frac{A}{P} = \frac{262.5}{36.8} = 7.13 \, ft$$

Solve Manning's equation.

$$q = \frac{1.486}{n} A r_h^{2/3} S^{1/2} = \frac{1.486}{0.02}(262.5)(7.13)^{2/3}(0.0008)^{1/2} = 2042 \, ft^3/s$$

Another equation that can be used to calculate the flow rate in open channels is the Hazen–Williams equation. It is given by

$$v \text{ (ft/s)} = 1.318 \, n r_h^{0.63} S^{0.54}$$

or

$$q \text{ (ft}^3\text{/s)} = 1.318 n A r_h^{0.63} S^{0.54}$$

Illustrative Example 28.7   A watershed has an area of $8 \, mi^2$. On average, rainfall occurs every 3 days at a rate of 0.06 mL/day and for a period of 5 h. Approximately 50% of the rain runoff reaches the sewers and contains an average total nitrogen concentration of 9.0 mg/L. In addition, the city wastewater treatment plant discharges 10 MGD (10^6 gal/day) with a total nitrogen concentration of 35 mg/L. Compare the total nitrogen discharge from runoff from the watershed with that of the city's sewage treatment plant.

Solution   First calculate the total nitrogen discharge, $\dot{m}_w$, from the treatment plant:

$$\dot{m}_w = (10)(35)(8.34)$$
$$= 2919 \, \text{lb/day}$$

The volumetric flow of the runoff, q, is

$$q = (0.5)(0.06)(8)(5280)^2/(3600)(12)$$
$$= 155 \, \text{ft}^3/\text{s}$$

The total nitrogen discharge, $\dot{m}_r$, from runoff is then

$$\dot{m}_r = \left(155 \, \text{ft}^3/\text{s}\right)(9 \, \text{mg/L})\left(10^{-6} \, \text{L/mg}\right)(3600 \times 24 \, \text{s/day})\left(62.4 \, \text{lb/ft}^3\right)$$
$$= 7521 \, \text{lb/day}$$

During rain, the runoff is over 2.5 times that for the treatment plant.

Illustrative Example 28.8   A municipality generates 1000 lb of solids daily. Size an aerobic digester to treat the solids. The following design parameters and information are provided:

Detention time, hydraulic $= t_h = 20$ days, etc.
Detention time, solids $t_s = 20$ days;
Temperature $= 95°F$;
Organic loading (OL) $= 0.2 \, \text{lbVS}/(\text{ft}^3 \cdot \text{day})$;
Volatile solids (VS) $= 78\%$ of total solids;
Percentage solids (TS) entering digester $= 4.4\%$;
VS destruction $= 62\%$.

Solution   Check the design based on the organic load and the hydraulic load. The volume based on the organic load, V_{OL}, is

$$V_{OL} = (1000)(0.78)/(0.2)$$
$$= 3900 \, \text{ft}^3$$

Based on the hydraulic load the volume, V_{HL}, is

$$V_{HL} = \frac{(1000)(20)}{(0.044)(8.33)(7.48)}$$
$$= 7300 \, \text{ft}^3$$

Since 7300 > 3900, the hydraulic detention time controls and the design volume is 7300 ft³.

Illustrative Example 28.9 A large, deep cavern (formed from a salt dome), located north of Houston, Texas, has been proposed as an ultimate disposal site for both solid hazardous and municipal wastes. Preliminary geological studies indicate that there is little chance that the wastes and any corresponding leachates will penetrate the cavern walls and contaminate adjacent soil and aquifers. A risk assessment analysis was also conducted during the preliminary study and the results indicate that there was a greater than 99% probability that no hazardous and/or toxic material would "meander" beyond the cavern walls during the next 25 years.

The company preparing the permit application for the Texas Water Pollution Board has provided the following data and information:

Approximate total volume of cavern = 0.78 mi³.
Approximate volume of cavern available for solid waste depository = 75% of total volume.
Proposed maximum waste feed rate to cavern = 20,000 lb/day.
Feed rate schedule = 6 days/week.
Average bulk density of waste = 30 lb/ft³.

Based on the above data, estimate the minimum amount of time it will take to fill the volume of the cavern available for the waste deposition.

Note: The proposed operation could extend well beyond the 25 years upon which the risk assessment analysis was based. The decision whether to grant the permit is somewhat subjective since there is a finite, though extremely low, probability that the cavern walls will be penetrated. Another, more detailed and exhaustive, risk analysis study should be considered.

Solution The volume of the cavern, V, in cubic miles available for the solid waste is

$$V = (0.75)(0.78)$$

$$= 0.585 \, mi^3$$

This volume can be converted to cubic feet:

$$V = (0.585 \, mi^3)(5280 \, ft/mi)^3$$

$$= 8.61 \times 10^{10} \, ft^3$$

The daily volume rate of solids deposited within the cavern in cubic feet/day, q, is

$$q = (20,000 \, lb/day)/(30 \, lb/ft^3)$$

$$= 667 \, ft^3/day$$

The solids volume rate can now be converted to cubic feet/year:

$$q = (667\,\text{ft}^3/\text{day})(6\,\text{days/week})(52\,\text{weeks/yr})$$

$$= 208{,}000\,\text{ft}^3/\text{yr}$$

The time it will take to fill the cavern is therefore

$$t = V/q$$

$$= 8.61 \times 10^{10}/208{,}000$$

$$= 414{,}000\,\text{yr}$$

Deep-well injection is an ultimate disposal method that transfers liquid wastes far underground and away from freshwater sources. Like landfarming, this disposal process has been used for many years by the petroleum industry. It is also used to dispose of saltwater in oil fields. When the method first came into use, the injected brine would often eventually contaminate groundwater and freshwater sands because the site was poorly chosen. The process has since been improved, and laws such as the Safe Drinking Water Act of 1974 ensure that sites for potential wells are better surveyed.

Illustrative Example 28.10   A compliance stack test on a facility yields the results provided below in Table 28.3. Determine whether the incinerator meets the state particulate standard of 0.05 gr/dscf. Estimate the amount of particulate matter escaping the stack, and indicate the molecular weight of the stack gas. Use standard conditions of 70°F and 1 atm pressure.

Table 28.3   Compliance test data

Volume sampled	35 dscf
Diameter of stack	2 ft
Pressure of stack gas	29.6 in Hg
Stack gas temperature	140°F
Mass of particulate collected	0.16 g
% moisture in stack gas	7% (by volume)
% O_2 in stack gas (dry)	7% (by volume)
% CO_2 in stack gas (dry)	14% (by volume)
% N_2 in stack gas (dry)	79% (by volume)
Pitot tube factor (k)	0.85

Pitot tube measurements made at eight points across the diameter of the stack provided values of 0.3, 0.35, 0.4, 0.5, 0.5, 0.4, 0.3, and 0.3 in of H_2O.

Use the following equations for S-type pitot tube velocity, v (m/s), measurements (see also Equation (19.9)):

$$v = C\sqrt{2gH}$$

$$= C\sqrt{2g\frac{\rho_l}{\rho}(0.0254)h}$$

where g = gravitational acceleration (9.81 m/s^2)
        H = fluid velocity head, in H$_2$O
        ρ_l = density of manometer fluid, 1000 kg/m^3
        ρ = density of flue gas, 1.084 kg/m^3
        h = mean pitot tube reading, in H$_2$O
        C = pitot tube coefficient = 0.85 (dimensionless)

Solution   The particulate concentration in the stack is

$$\text{Particulate concentration} = \frac{0.16\,\text{g collected}}{35\,\text{dscf sampled}} \left(\frac{15.43\,\text{gr}}{\text{g}} \right)$$

$$= 0.0706\,\text{gr/dscf}$$

Since this does exceed the particulate standard of 0.05 gr/dscf, *the facility is not in compliance*.

The actual particulate emission rate is the product of the stack flowrate and the stack flue gas particulate concentration. The stack flowrate is calculated from the velocity measurements provided in the problem statement using the second velocity equation given.

$$v = 0.85 \sqrt{2(9.81\ \text{m/s}^2)\left(\frac{1000\ \text{kg/m}^3}{1.084\ \text{kg/m}^3}\right)0.0254h}$$

$$= 0.85(21.4)\sqrt{h}$$

$$= 0.85(21.4)(0.6142)$$

$$= 11.2\ \text{m/s} = 36.75\ \text{fps}$$

$$\text{Stack flowrate} = v\,(\text{cross-sectional area})$$

$$v = 36.75\ \text{fps}\left(\frac{\pi}{4}\right)(2\ \text{ft})^2$$

$$= 115.45\ \text{acfs} = 6.924\ \text{acfm}$$

$$\text{Dry volumetric flowrate} = (1-0.07) \times 6924\ \text{acfm} = 6439\ \text{dacfm}$$

Correct to standard conditions of 70°F and 1 atm pressure:

$$\text{Standard volumetric flowrate} = 6439\ \text{dacfm}\left(\frac{530°\text{R}}{600°\text{R}}\right)\left(\frac{29.6\ \text{psi}}{29.9\ \text{psi}}\right)$$

$$= 5631\ \text{dscfm}$$

Particulate emission rate $= 0.0706\,\text{gr/dscf}(5631\,\text{dscfm})$
$$= 398\,\text{gr/min}$$
$$= 398\,\text{gr/min}\left(\frac{1\,\text{lb}}{7000\,\text{gr}}\right) = 0.0569\,\text{lb/min}$$
$$= (0.0569\,\text{lb/min})(1440\,\text{min/day}) = 81.9\,\text{lb/day}$$

The molecular weight of flue gas is based on the mole fraction of the flue gas components. The flue gas is 7% water and 93% other components by volume. On a dry basis, the flue gas molecular weight is

$$MW = 0.07\,O_2(32\,\text{lb/lbmol}) + 0.14\,CO_2(44\,\text{lb/lbmol}) + 0.79\,N_2(28\,\text{lb/lbmol})$$
$$= 30.52\,\text{lb/lbmol}$$

The average molecular weight of the stack gas on an actual (wet) basis is then

$$MW = 0.07\,\text{water}(18\,\text{lb/lbmol}) + 0.93\,\text{other components}(30.52\,\text{lb/lbmol})$$
$$= 29.64\,\text{lb/lbmol}$$

Illustrative Example 28.11   Perchloroethylene (PCE) is utilized in a degreasing operation and is lost from the process via evaporation from the degreasing tank. This process has an emission factor (estimated emission rate/unit measure of production) of 0.78 lb PCE released per lb PCE entering the degreasing operation. The PCE entering the degreaser is made up of recycled PCE from a solvent recovery operation plus a fresh PCE makeup. The solvent recovery system is 75% efficient with the 25% reject going offsite for disposal.

1. Draw a flow diagram for the process.
2. Develop a mass balance around the degreaser.
3. Develop a mass balance around the solvent recovery system.
4. Develop a mass balance around the entire system.
5. Determine the mass of PCE emitted per pound of fresh PCE utilized.

Quantify the impact of the emission factor in the degreasing operation on the flowrates within the solvent recovery unit.

Solution

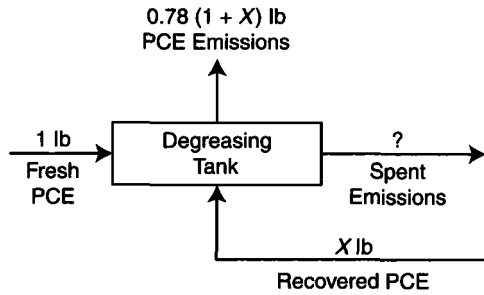1. A flow diagram for the system is provided in Fig. 28.1.

Figure 28.1   PCE mass balance around degreasing tank.

2. Assume a basis of 1 lb of fresh PCE feed. A PCE mass balance around the degreasing tank can now be written for the unit pictured in Fig. 28.1.

$$\text{Input} = \text{Fresh} - \text{Recycled PCE}$$
$$= 1 \text{ lb} + X \text{ lb}$$
$$\text{Output} = \text{PCE emissions} + \text{Spent PCE}$$
$$= 0.78(1 + X) + \text{Spent PCE}$$

Equating the input with the output gives

$$\text{Spent PCE} = (1 - 0.78)(1 + X)$$
$$= 0.22(1 + X) \text{ lb PCE}$$

3. A PCE mass balance around the solvent recovery unit is shown in Fig. 28.2.

$$\text{Input} = \text{Spent PCE}$$
$$= 0.22(1 + X) \text{ lb}$$
$$\text{Output} = \text{Recycle PCE} + \text{Reject PCE}$$

where

$$\text{Recycle PCE} = 75\% \text{ of spent PCE}$$
$$= 0.75[0.22(1 + X)] + \text{Reject PCE}$$

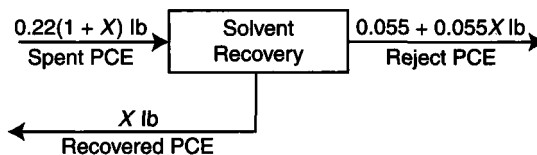**Figure 28.2**   PCE mass balance around solvent recovery unit.

Since

$$\text{Input} = \text{Output}$$
$$0.22(1 + X) = 0.75[0.22(1 + X)] + \text{Reject PCE}$$
$$\text{Reject PCE} = (1 - 0.75)[0.22(1 + X)]$$
$$= 0.055 + 0.055X \text{ lb}$$

4. PCE mass balance around the entire system is shown in Fig. 28.3.

$$\text{Input} = 1 \text{ lb PCE}$$
$$\text{Output} = \text{PCE emissions} + \text{Spent PCE}$$
$$= (0.78 + 0.78X) + (0.055 + 0.055X)$$

Since

$$\text{Input} = \text{Output}$$
$$1 \text{ lb PCE} = (0.78 + 0.78X) + (0.055 + 0.055X)$$
$$= 0.835 + 0.835X$$
$$X = 0.165/0.835$$
$$= 0.198 \approx 0.20 \text{ lb PCE}$$

5. From the flow diagram in Fig. 28.3:

$$\text{PCE emissions} = 0.78 + 0.78X$$
$$= 0.78 + 0.78(0.20)$$
$$= 0.94 \text{ lb PCE emitted per lb fresh PCE}$$

If the emission factor were lower, the flowrates to the solvent recovery unit and the recycle stream would be higher. Additionally, there would be less PCE lost from the system. To determine the effect of the emissions factor on the system flow streams,
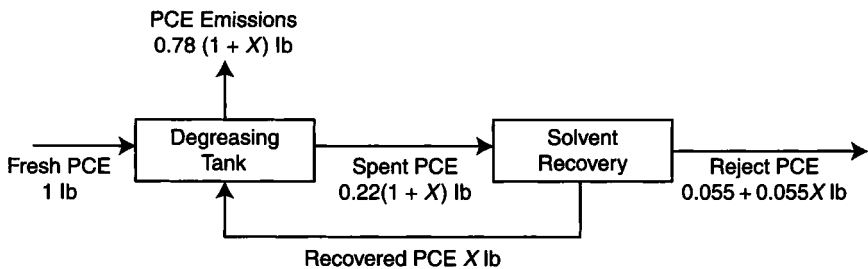

Figure 28.3   PCE mass balance around entire system.

the equations above were solved using three different emission factors: 0.78, 0.60, and 0.40. These results are summarized below in Table 28.4.

Table 28.4   PCE emission results

Emission Factor	0.78	0.60	0.40
Fresh PCE	1.0	1.0	1.0
Recovered PCE	0.198	0.429	0.818
Spent PCE	0.263	0.571	1.091
PCE emissions	0.934	0.857	0.727
Reject PCE	0.066	0.142	0.273

The sum of the recovered and fresh PCE provides a measure of the degreasing capability of the system per kilogram feed. Notice that, as the emission factors decrease, this sum goes up significantly.

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