ENVIRONMENTAL PROTECTION AGENCY

APTI 413: Control of Particulate Matter Emissions

Student Manual
Chapter 5

APTI: 413 CONTROL OF PARTICULATE MATTER EMISSIONS, 5TH EDITION

Student Manual

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The preparation of this manual was overseen by the organizations of the Environmental Protection Agency (EPA) and the National Association of Clean Air Agencies (NACAA*), and the revision of materials was coordinated and managed by the Tidewater Operations Center of C^2 Technologies, Inc., Newport News, Virginia.

Valuable research and feedback was provided by an advisory group of subject matter experts composed of Dr. Jerry W. Crowder, TX; Dr. Tim Keener, OH; Dr. Douglas P. Harrison, LA., and Mr. Tim Smith, Senior Air Quality Specialist, EPA, Office of Air Quality Planning and Standards.

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**The National Association of Clean Air Agencies (NACAA) represents air pollution control agencies in 53 states and territories and over 165 major metropolitan areas across the United States.*

State and local air pollution control officials formed NACAA (formerly STAPPA/ALAPCO) over 30 years ago to improve their effectiveness as managers of air quality programs. The associations serve to encourage the exchange of information among air pollution control officials, to enhance communication and cooperation among federal, state, and local regulatory agencies, and to promote good management of our air resources.

Table of Contents

Chapter
5

This chapter will take approximately 45 minutes to complete.

OBJECTIVES

Terminal Learning Objective

At the end of this chapter, the student will be able to discuss the operation of settling chambers and use performance evaluation equations to estimate expected collection efficiency.

Enabling Learning Objectives

5.1 Distinguish between different types of settling chambers.

5.2 Use performance evaluation equations to estimate expected collection efficiency of a settling chamber.

Checks on Learning

Chapter Examples
And
End of Chapter Review

Settling Chambers

Long used by industry for removing solid or liquid particles from gaseous streams, settling chambers have the advantages of simple construction, low initial cost, low maintenance, low pressure drop and simple disposal of collected materials. It was one of the first devices used to control particulate emissions and is simply an expansion chamber in which gas velocity is reduced, allowing time for particles to settle out under the action of gravity. The settling chamber, however, is generally limited to the removal of particles larger than about 40-60 μm diameter. Today's demands for cleaner air and stricter emission standards have relegated the settling chamber to use as a pre-cleaner for other particle control devices.

5.1 Types and Components

There are basically two types of settling chambers: the *simple expansion chamber* and the *multiple-tray* settling chamber. Momentum separators cause the gas to change directions and add a downward inertial force to supplement the gravitational force. A typical simple expansion settling chamber is shown in Figure 5-1. The unit is constructed in the form of a long horizontal box with a gas inlet and outlet and dust collection hoppers. The particle-laden gas stream enters the unit at the gas inlet and flows into an expansion section. Expansion of the gas stream causes the gas velocity to be reduced to the chamber velocity. As the gas flows through the chamber, particles in the gas stream are subjected to the force of gravity and settle into the dust collection hoppers. The principal parameters that control collection efficiency are the settling time of the particles and residence time in the chamber. Theoretically, a settling chamber of infinite length could collect even very small particles. The collection hoppers located at the bottom of the settler are usually designed with positively sealing valves and should be emptied as the dust is collected to avoid re-entrainment problems.

Howard Settling Chamber

The multiple-tray settling chamber, also called the Howard settling chamber, is shown in Figure 5-2. Several collection plates are introduced to shorten the settling path of the particles and to improve the collection efficiency of smaller particles. Although the trays are shown as horizontal, they are typically angled vertically upward to provide for gravity cleaning. The gas must be uniformly distributed as it flows through the passageways created by the trays. Uniform distribution is usually achieved by the use of gradual transitions, guide vanes and perforated plates or screens.

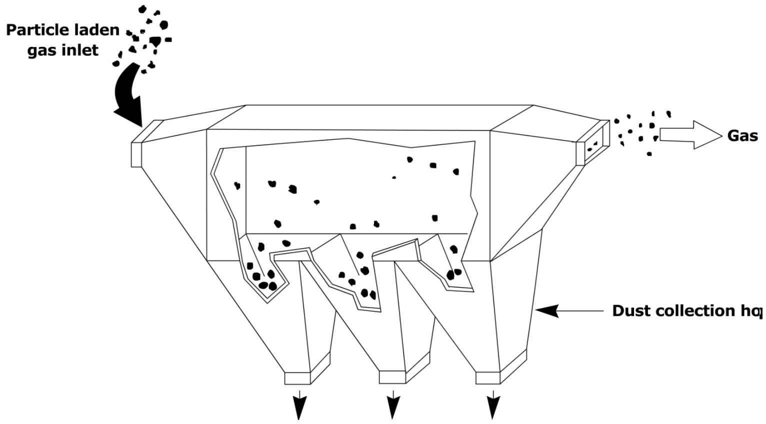


Figure 5-1. Horizontal flow settling chamber

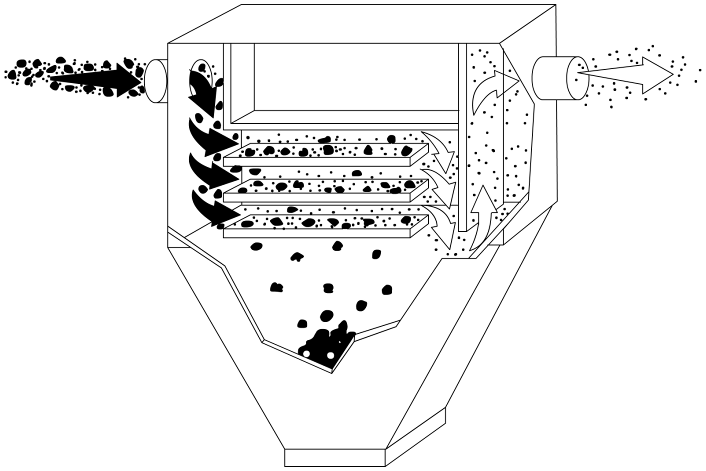
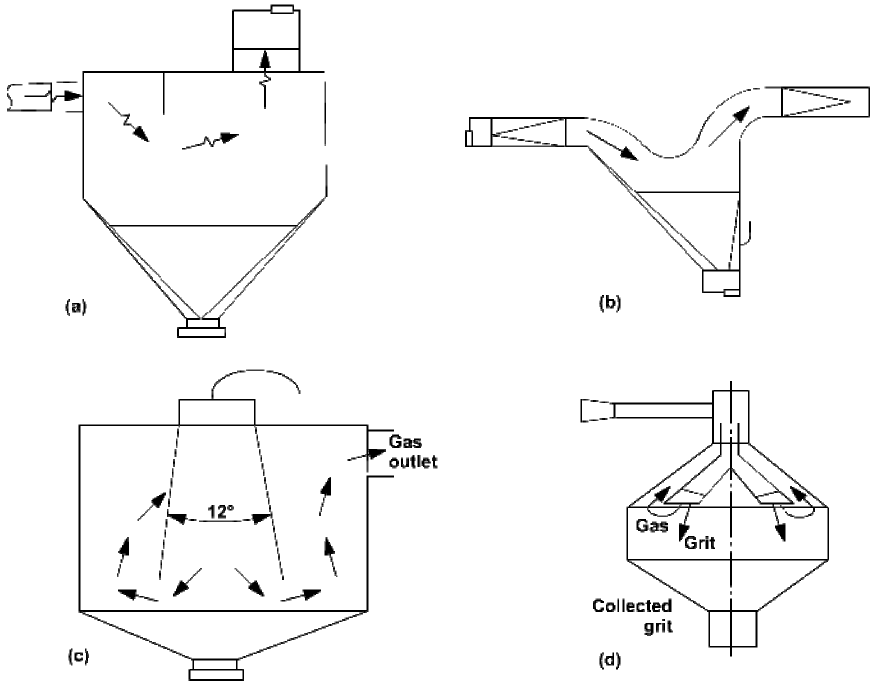


Figure 5-2. Multi-tray settling chamber

Momentum Separators



5.2 Performance Evaluation

Understanding the principles governing particle collection in a settling chamber begins by examining the behavior of a single spherical particle in the chamber (see Figure 5-3). The gas velocity is assumed to be uniform throughout the chamber, and the particles move horizontally at the gas stream velocity, v_g. The particle also has a downward vertical velocity as a result of the effect of gravity. This is the terminal settling velocity, v_t discussed in Chapter 4.

Suppose a particle enters the chamber at a height, h_p. The particle must fall this distance before it travels the length of the chamber, if the particle is to be collected. In other words, the particle will be collected if the time required for the particle to settle is less than the time that the particle resides in the chamber.

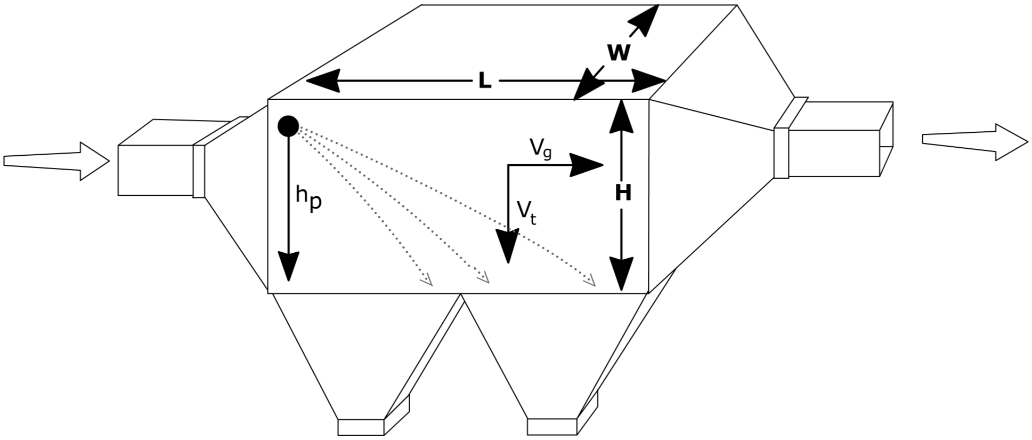


Figure 5-3. Settling chamber dimensions

Unfortunately, it is not as simple as the above scenario would suggest. The Reynolds number at chamber conditions is very high, indicating very turbulent conditions. Instead of particles settling directly into the hopper, they may settle a short distance, encounter a turbulent eddy, and be carried back upward to begin settling again as the eddy velocity decreases. The general form for determining collection efficiency when the flow is turbulent is:

(5-1)

$$\eta_i = 1 - e^{-x}$$

Where

η_ι= collection efficiency for one size particle (fractional)

For a simple settling chamber:

(5-2)

$$X_i = \frac{t_r}{t_{s_i}}$$

Where

t_r= chamber residence time

t_{si}= particle settling time

The chamber residence time is determined from the gas velocity and the chamber length:

(5-3)

$$t_r = \frac{L}{v_g}$$

Where

L = chamber length (ft)

v_g= gas velocity (ft/sec)

The gas velocity is determined from the gas flow rate and the width and height of the chamber.

(5-4)

$$v_g = \frac{Q}{WH}$$

Where

Q = gas flow rate (ft^3/sec)
W = chamber width (ft)
H = chamber height (ft)

Substituting Equation 5-4 into Equation 5-3 gives:

(5-5)

$$t_r = \frac{LWH}{Q}$$

The particle settling time is determined from the particle terminal settling velocity and, in the worst case, the chamber height:

(5-6)

$$t_s = \frac{H}{v_t}$$

Where

H= chamber height (ft)
v_t = particle terminal settling velocity (ft/sec)

Simple settling chambers have

N = 1

Multi-tray settling chambers have

N = nTrays +1

Substituting Equations 5-5 and 5-6 into Equation 5-2 and then substituting that into Equation 5-1 gives:

(5-7)

$$\eta_i = 1 - e^{-\frac{v_1 LW}{Q}}$$

To expand the applicability of Equation 5-7 to multi-tray settling chambers, we can add the parameter N_c, the number of parallel passageways through the chamber. For a simple settling chamber, N_c is one. For a multi-tray settling chamber, N_c is the number of trays plus one. The final relationship for the efficiency of a settling chamber then becomes:

(5-8)

$$\eta_i = 1 - e^{\frac{-v_1 LWN_c}{Q}}$$

Recall from Chapter 4 that the terminal settling velocity of a particle in a laminar region ($Re_p<1$) is given by (C_c is assumed to be 1):

(5-9)

$$v_t = \frac{g\rho_p d^2 p_i}{18\mu_g}$$

Where

v_t = particle terminal settling velocity (ft/sec)
g = acceleration of particle due to gravity (32.17 ft/sec^2)
ρ_p= particle density (lb$_m$/ft^3)
μ_g= gas viscosity (lb$_m$ /(ft·sec))
d_p= physical particle diameter (ft)

Particles that are smaller than 100 μm generally fall into this region. However, the linear relationship for drag coefficient can be extended into the transition region, up to a particle Reynolds number of about 5-10, without introducing significant error. This allows Equation 5-9 to be approximately applied to particles considerably larger than 100 μm. The error introduced by this assumption should be checked and, if it is significant, the terminal settling velocity for the transition region should be used where appropriate.

Substituting Equation 5-9 into Equation 5-8 give the collection efficiency relationship for particles in the laminar region:

(5-10)

$$\eta_i = 1 - e^{-\left(\frac{g\rho LWN_c}{18\mu_g Q}\right)d_{pi}^2}$$

Example 5-1 Estimate the collection efficiency of a 75 μm diameter particle in a simple settling chamber 10 ft wide by 10 ft high by 30 ft long when the gas velocity through the chamber is 5 ft/sec. Assume a particle density of 120 lb$_m$/ft^3 and gas stream conditions of 68°F and 1 atm.

Solution

Convert particle size to feet:

$$d_p = 75\mu m\left(\frac{ft}{0.3048x10^{6}\,\mu m}\right) = 2.46x10^{-4}\,ft$$

Calculate volumetric flow rate:

$$Q = v_g WH = \left(5\frac{ft}{sec}\right)(10ft)(10ft) = 500\frac{ft^3}{sec}$$

Calculate collection efficiency:

$$\eta_i = 1 - e^{-\left(\frac{g\rho_p W N_c}{18\mu_g Q}\right)d_{pi}^2} = 1 - e^{-\left[\frac{\left(32.17\,{}^{ft}\!/_{sec^2}\right)\left(120\,{}^{lb_m}\!/_{ft^3}\right)(30ft)(10ft)(1)}{18\left(1.21x10^{-5}\,{}^{lb_m}\!/_{ft\cdot sec}\right)}\right]\left(2.46x10^{-4}\,ft\right)^2}$$

$$= 0.475 = 47.5\%$$

The design variables for a settling chamber include the length, width and height of the chamber. These parameters are chosen by the equipment manufacturer to remove all particles above a specified size. The chamber design must provide conditions for sufficient residence time to capture the desired particle size range. This can be accomplished by keeping the velocity of the gas through the chamber as low as possible. If the velocity is too high, dust re-entrainment will occur. However, the design velocity should not be so low as to cause the chamber volume to be exorbitant. Accordingly, units are typically designed for gas velocities in the range of 1 to 10 ft/sec.

In settling chamber designs, the velocity at which the gas moves through the chamber is usually called the throughput velocity. The velocity at which settled particles become re-entrained is called the pickup velocity. In order to avoid re-entrainment of collected dust, the throughput velocity must not exceed the pick up velocity. Pickup velocities for several materials are given in Table 5-1. If no data are available, the pickup velocity should be assumed to be 10 ft/sec. In this case, the gas velocity through the chamber must be less than 10 ft/sec.

Table 5-1. Pickup Velocities of Various Materials

Material	Density	Median Size	Pickup Velocity
Aluminum chips	2.72	335	14.2
Asbestos	2.20	261	17.0
Nonferrous foundry	3.02	117	18.8
Lead oxide	8.26	15	25.0
Limestone	2.78	71	21.0
Starch	1.27	64	5.8
Steel shot	6.85	96	15.2
Wood chips	1.18	1,370	13.0
Sawdust	---	1,400	22.3

Summary

All air pollution control devices have advantages and disadvantages. Below is a quick list of both for Settling Chambers.

Advantages:

- Low Capital Cost
- Very Low Energy Cost
- No Moving Parts
- Few Maintenance Requirements
- Low Operating Costs
- Excellent Reliability
- Low Pressure Drop
- Device Not Subject to Abrasion
- Provides Incidental Cooling of Gas Stream
- Dry Collection and Disposal

Disadvantages:

- Relatively Low PM Collection Efficiencies
- Unable to Handle Sticky or Tacky Materials
- Large Physical Size
- Trays in Multiple-Tray Settling Chamber may Warp

Review Questions

1. Identify the primary force responsible for particle collection in settling chambers.
    a. electrostatic
    b. impaction
    c. centrifugal
    d. gravity
    e. Brownian diffusion

2. Settling chambers are normally effective for removing particles in which of the following size ranges.
    a. less than 10 microns
    b. between 10 and 50 microns
    c. greater than 70 microns
    d. submicron particles only

3. Increasing the gas volumetric feed rate to an existing settling chamber would be expected to result in
    a. a decrease in collection efficiency
    b. an increase in collection efficiency
    c. no change in collection efficiency
    d. impossible to say

Review Questions

4. Identify the primary force responsible for particle collection in settling chambers.
    a. electrostatic
    b. impaction
    c. centrifugal
    d. gravity
    e. Brownian diffusion

5. Settling chambers are normally effective for removing particles in which of the following size ranges.
    a. less than 10 microns
    b. between 10 and 50 microns
    c. greater than 70 microns
    d. submicron particles only

6. Increasing the gas volumetric feed rate to an existing settling chamber would be expected to result in
    a. a decrease in collection efficiency
    b. an increase in collection efficiency
    c. no change in collection efficiency
    d. impossible to say

Review Problems

Estimate the collection efficiency of a 50 μm diameter particle in a simple settling chamber 5 meters wide by 2 meters high by 10 meters long when the gas velocity is 0.3 m/sec. Assume a particle density of 4.6 g/cm^3 and gas stream conditions of 20°C and 1 atm.

Review Problem Solutions

Estimate the collection efficiency of a 50 μm diameter particle in a simple settling chamber 5 meters wide by 2 meters high by 10 meters long when the gas velocity is 0.3 m/sec. Assume a particle density of 4.6 g/cm^3 and gas stream conditions of 20°C and 1 atm.

Solution

Calculate the volumetric flow rate:

$$Q = v_g WH = \left(0.3\frac{m}{\sec}\right)(5m)(2m) = 3.0\frac{m^3}{\sec} = 3.0x10^6\frac{cm^3}{\sec}$$

Calculate collection efficiency:

$$\eta_i = 1 - e^{-\left(\frac{g\rho_L W N_c}{18\mu_g Q}\right)d_{p_i}^2} = 1 - e^{-\left[\frac{\left(980\,{}^{\text{ft}}\!/_{\sec^2}\right)\left(120\,{}^{\text{lb}_\text{m}}\!/_{\text{ft}^3}\right)(1000\text{ft})(500\text{ft})(1)}{18\left(1.80\text{x}10^{-4}\,{}^{\text{g}}\!/_{\text{cm}\cdot\sec}\right)\left(3.0x10^6\frac{cm^3}{\sec}\right)}\right]\left(50\text{x}10^{-4}\,\text{ft}\right)^2}$$

= 0.997 = 99/7%

References

Beachler, D.S., and J.A. Jahnke, *Control of Particulate Emissions*, APTI Course 413 Student Manual, EPA 450/2-80-066, October 1981.