GATOR TRAX:
AIR POLLUTION PROJECT

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Goal: This project is designed to introduce middle and high school students to the field of environmental engineering, and specifically air pollution control. Students will learn basic information about one of the most commonly used air pollution control devices available in industries – the baghouse. In the process, mathematics will be used to determine the efficiencies of simulated baghouses that are created using simple items available from any hardware store.

I. Background

Air Pollution

Air pollution is defined as an atmospheric condition in which *substances* are present at concentrations higher than their normal levels to produce a *measurable* effect on humans, animals, vegetation, or materials. These air pollutants can be of any phase – gas, liquid or solid. Air pollutants that are in the liquid and/or solid phases are referred to as particles or particulate matter (PM).

The sizes and chemical compositions of air pollutants vary greatly, and are dependent on the sources. In general, gases are several angstroms (Å, or 10^{-10} meters) in size, and particles can vary from molecular dimensions (~2 Å) up to approximately 500 μm. In order to place these sizes into perspective, one can consider a human hair, which is typically about 100 μm in diameter. Particles can be classified according to their size. Those that are less than 2.5 μm in diameter are denoted as being “fine” particles, and those greater than 2.5 μm are “course” particles. (Note: A common term that is often interchanged with “particles” is the term “aerosols’. Aerosols are particles that are suspended in air.)

Air pollutants originated from a variety of sources, either biogenic or anthropogenic in nature. Biogenic sources consist of trees, oceans, and volcanoes (among others), while examples of anthropogenic sources include cars, buses, trucks, and power plants. Each of these sources is capable of directly emitting air pollutants which can subsequently react in the atmosphere to form secondary air pollutants that are either gases or particles.

Baghouses

Baghouses are typically used in industrial settings to remove particulate matter (PM) from air streams. These baghouses employ surface filters (cloth bags) that help to trap the PM through the formation of a particle “cake” that aids in filtration. Figure 1 illustrates this point.

Commercial baghouses consist of four primary sections:

- an inlet for dirty (particle laden) air
- filter bags
- a collection hopper
- an outlet for clean (filtered) air

A typical schematic for a baghouse appears in Figure 2. This baghouse contains cylindrical cloth bags that are hung from a support and closed at the top. The bottom section of the bag is fit over cylindrical "sleeves" that project upwards from a cell plate that is located at the bottom of the baghouse.

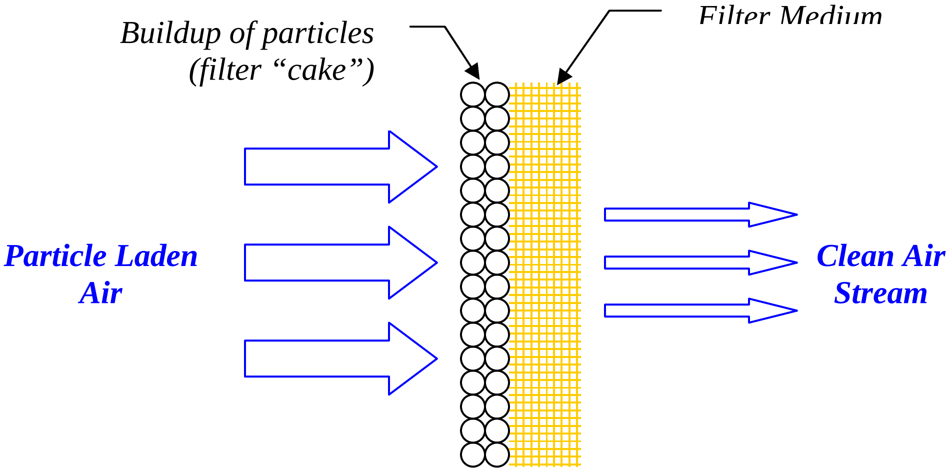


Figure 1: Flow through a surface filter.

Particle laden air enters the baghouse inlet and is directed underneath the cell plate. The dirty air then enters the filter bags, where the particles are trapped onto the cloth filter material, and air passes through the bag to the outlet. As the thickness of the filter cake increases (in the interior of the bags), the pressure drop through the baghouse increases. At a specific maximum pressure drop, the baghouse is temporarily taken out of service, and the filter bags are shaken to

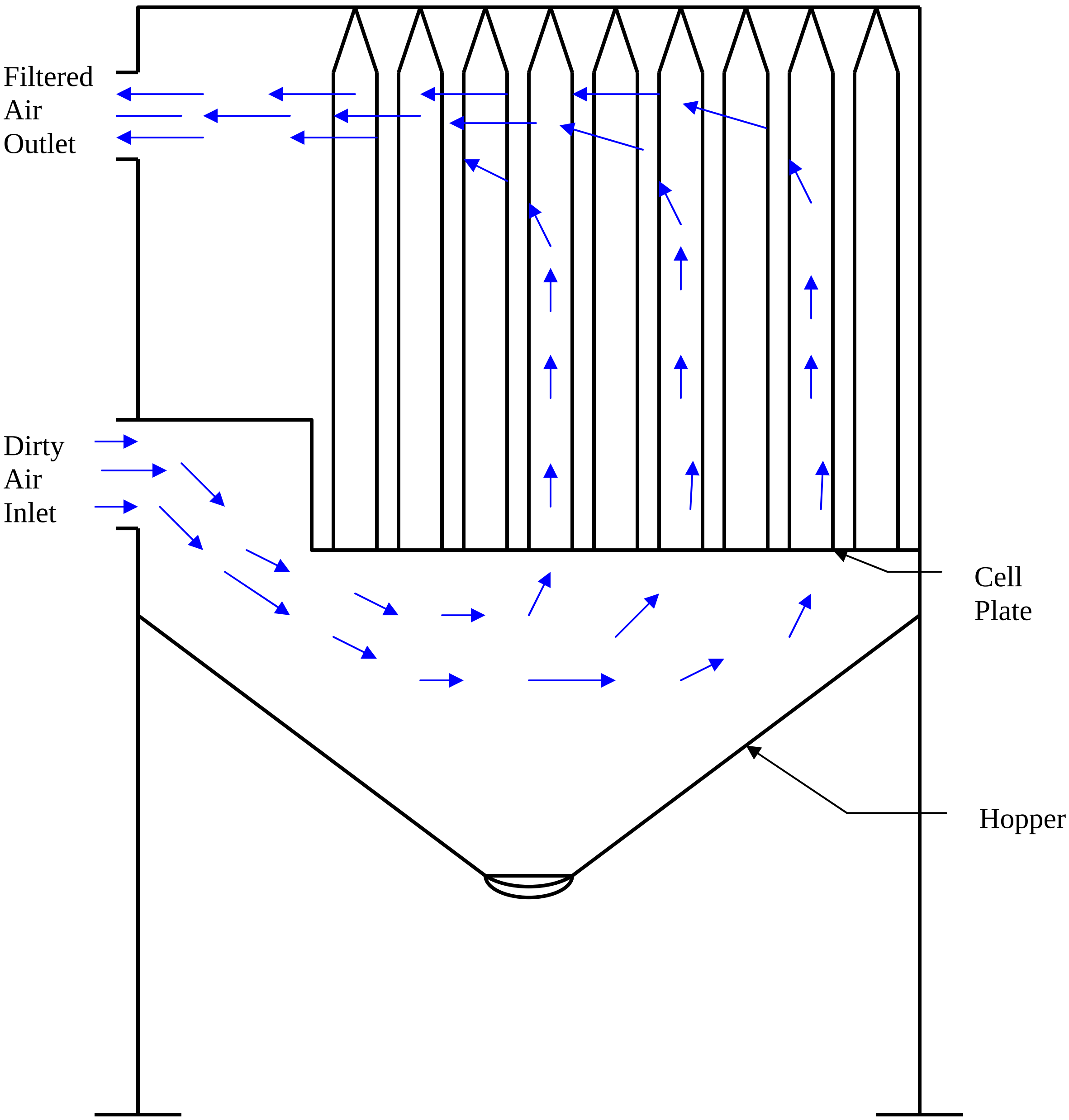


Figure 2: Schematic of a baghouse.

dislodge the filter cake. The particles in the filter cake fall into the collection hopper where they are stored. Typically, power plants collect these particles and sell them to cement companies for use as filler material.

II. Basic Mathematical Calculations

If one baghouse is operated alone, the efficiency of collection, η, in percent, can be defined as:

$$\eta = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \text{ x } 100 \qquad \text{(Eqn. 1)}$$

where C_{inlet} = inlet particle concentration in the air
C_{outlet} = outlet particle concentration in the air.

If there are multiple baghouses in series, then the overall collection efficiency (in fractional form), $\eta_{overall}$, can be expressed as:

$$\eta_{overall} = 1 - (1 - \eta_i)^N \qquad \text{(Eqn. 2)}$$

where η_i = the collection efficiency (in a fractional form) of one baghouse
N = the number of baghouses

It may be helpful to have the students derive Equation 2. This can be done rather easily by assuming that the inlet particle concentration to the first collector is “x”. If the first collector has efficiency, η_i, an amount, $x\eta_I$, will be collected, and $x- x\eta_i$ will exist at the outlet. This amount $(x- x\eta_i)$ enters the second collector, which has an efficiency of η_i. The outlet of the second collector is then $(x- x\eta_i)- \eta_i(x- x\eta_i)$. By factoring, the outlet of the second collector can be represented as $x(1-\eta_i)^2$. Since efficiency is defined as the amount collected (inlet-outlet concentrations) divided by the inlet concentration, the overall efficiency of two collectors in series is then:

$$\eta_{\text{two collectors in series}}=1-(1-\eta_i)^2. \qquad \text{(Eqn. 3)}$$

As the number of collectors increases to “N”, the overall collection efficiency for the entire system reduces to Equation 2.

There are other mathematical calculations that can be performed to actually design an appropriate baghouse for a given industrial system. However, those calculations are beyond the scope of this project for middle school students.

III. Project Details

A simulated baghouse system (with only one filter) can be designed and built by using materials that can be readily acquired at a hardware store. The materials that will be needed for the simulated baghouse system are listed in Table 1. A schematic of the proposed system appears in Figure 3.

After the simple filtration device is assembled, a blower can be attached to the end of the system, and particle laden air can be introduced to the system. Particles to use may include smaller particles such as baby powder, or larger particles such as wheat germ and oat flakes. In order to ensure that the particles that are used do not interfere with the blower, a small pore filter should be placed in line between the blower and the simulated baghouse system. Known masses of the particles should be introduced to the system using the particle introduction system (see Figure 4).

After a fixed period of flow, the blower should be turned off. This step would simulate the maintenance period that is used in industrial bag house systems. Since there will likely be particles trapped on the inside of the mesh screen, the students should be directed to gently shake the simulated baghouse system. This will simulate the “shake down” period that is used to clean the filter medium in industrial baghouses. Students can then weight the particles that are collected. The students should then calculate the efficiency of the simulated baghouse system by using Equation 1 and the mass data that are obtained.

Table 1: MATERIALS NEEDED TO CONSTRUCT A SIMPLE AIR FILTRATION DEVICE.

Item	Approx. Dimensions	Quantity	Comments
1 Gal Round Jar	4” o.d x 10” long	1	Using acrylic will allow the students to see the filtration taking place.
PVC tube	1” o.d. x 12” long	1	This piece is placed through the jar at the bottom of the jar up to the middle of the lid. It is sealed at the end which touches the middle of the lid. It is used to provide a structure onto which the mesh screen is attached.
PVC tube	1” o.d. x ~7” long	2	This piece is used at the top of the tube as an outlet. This tub goes through the lid and into the jar.
Mesh screen	2” wide x 10” long	1	Used as a filter medium. This material can be changed to cloth (such as burlap), vacuum cleaner bag material, or another porous material.
Glue/Hot glue gun		1	This is used to keep the mesh screen attached to 12” long PVC tube. Also used to seal off end of 12” long PVC tube to lid and any gaps between hole in bottom and top of jar and sides of PVC tube.
Small blower/Hair Dryer		1	Used to blow the particles through the system.
Funnel	½ pint	1	Used to assemble the particle introduction system. Air is blown into this funnel to stir up particles.
Oatmeal, baby powder	½ cup	1	Used as particulate matter in the bottom container/particle introduction system.

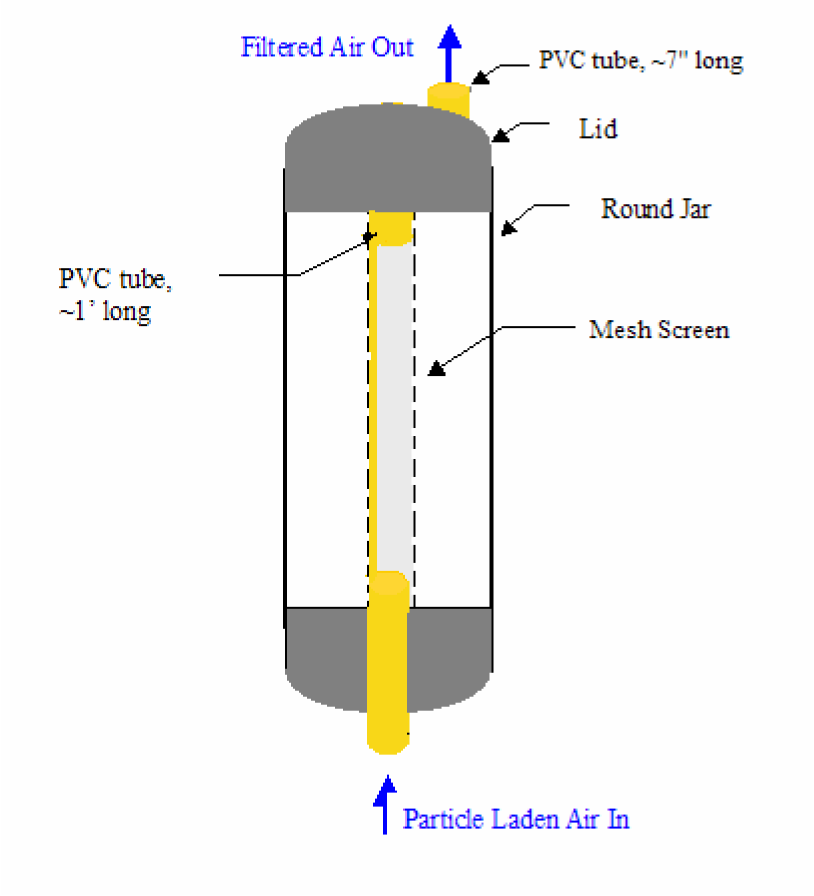


Figure 3: Simulated Baghouse System

IV. Modifications

There are several variations of this project that can be undertaken. One variation involves using a mixture of the particle types mentioned in section III rather than simply using one type of particle. Certain particles will be preferentially collected with a specific filter material, and the efficiency may change over time. Changes in the efficiency per unit time can be observed visually.

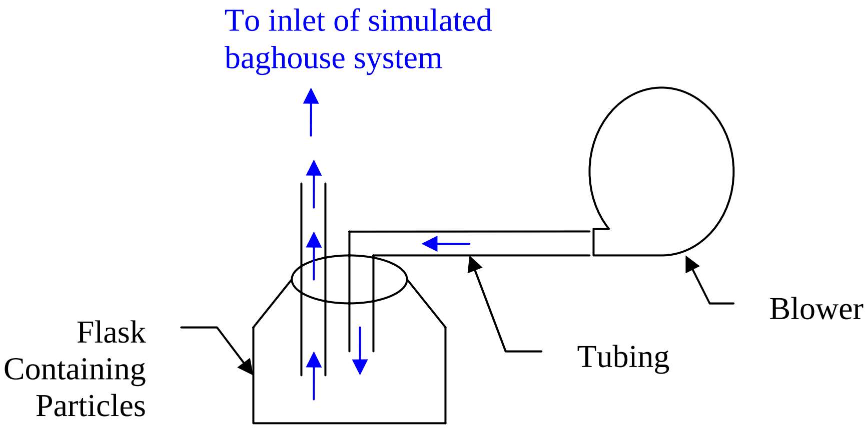


Figure 4: Schematic of the particle introduction system.

Another variation of the project involves using different filter materials. Rather than using a mesh screen, a vacuum cleaner bag, a sock, or a piece of burlap can be used within the simulated baghouse system. The efficiency of collection will likely change depending on the mesh size of the filter material.

A final variation of the project for middle school level students involves using a more powerful blower and assembling several simple baghouses in series. If the students perform experiments using this multiple system, they can then use Equation 2 to calculate an overall efficiency of the system.

The proposed simulated baghouse system can also be used to demonstrate higher order math skills that are typically encountered by high school students. Specifically, high school students can practice their use of logarithms. If the filter material is characterized so that the filtration efficiencies are known, then the students can determine the exact number of filter systems needed to remove a minimum level of particulate matter using a multiple filter system. The calculations rely on the use of Equation 2 and the properties of natural logarithms to calculate “N”. The resulting simplified equation for N is: $N = \ell n(\eta_i - \eta_{overall})$, if the efficiencies of each collector are identical at η_i. Example problem number 3 demonstrates

Sample Problem Statements

1. Math Concept Tested: Percentages

   A particle laden air stream contains 60 micrograms (μg) per cubic meter (m^3) of air. If 10 m^3 of this particle filled air flows through the particle collection system, and 20 $\mu g / m^3$ are collected, what is the efficiency of collection?

2. Math Concept Tested: Percentages, Algebra

   A stream of air contains particles at a concentration of 100 μg particles/ m^3 of air. A collector with 98% efficiency is used to remove particles from this air stream. What is the concentration of particles that are collected in the instrument? What is the concentration of particles that remain in the exit air stream?

3. Math Concept Tested: Factoring, logarithms

   A particle laden air stream contains 100 μg particles/ m^3 of air. If the particle concentration is to be reduced to 2 $\mu g / m^3$ using particle collectors, how many collectors must be used? Assume that (a) the collectors are placed in series, (b) each collector is identical, and (c) each collector has a collection efficiency of 75%.

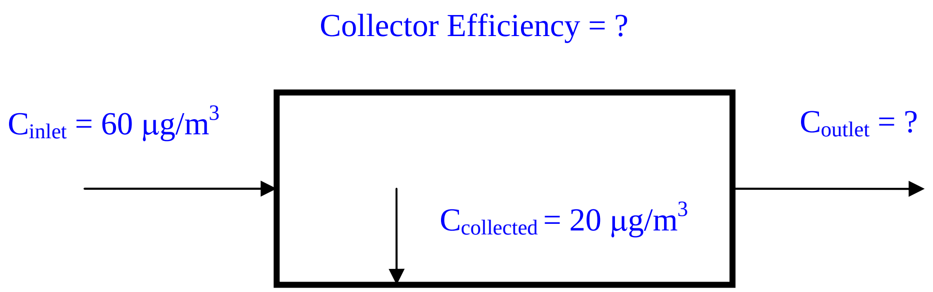
Solution: Problem #1

Problem Statement:

A particle laden air stream contains 60 micrograms (μg) per cubic meter (m^3) of air. If 10 m^3 of this particle filled air flows through the particle collection system, and 20 μg / m^3 are collected, what is the efficiency of collection?

Solution:

It is always helpful to start a problem by drawing a diagram and labeling the known/given quantities. The diagram for this problem would be:



The problem asks for the collection efficiency. Based on Equation 1, we know that the only parameters that are needed to determine the efficiency are the amount collected in the system and the inlet concentration. Recall that the amount collected can also be calculated by remembering that $C_{collected} = C_{inlet} - C_{outlet}$. However, we are given the collected particle concentration and the inlet concentration. Thus, the solution to the given problem is:

$$\eta = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \text{ x } 100$$

$$\eta = \frac{C_{collected}}{C_{inlet}} \text{ x } 100$$

$$\eta = \frac{20\,\mu g\, m^{-3}}{60\,\mu g\, m^{-3}} \text{ x } 100$$

$$\eta = 33\%$$

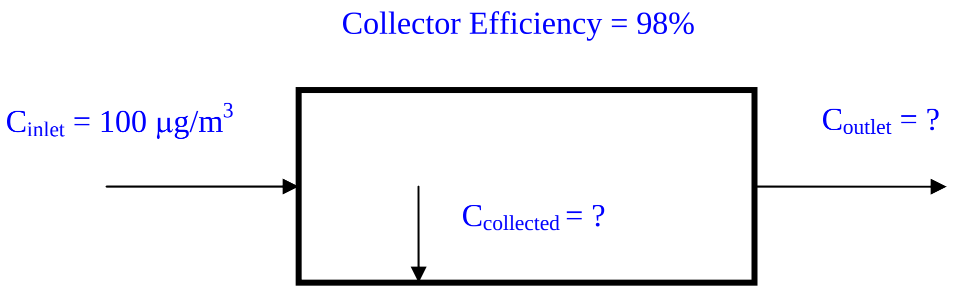
Solution: Problem #2

Problem Statement:

A stream of air contains particles at a concentration of 100 μg particles/ m^3 of air. A collector with 98% efficiency is used to remove particles from this air stream. What is the concentration of particles that are collected in the instrument? What is the concentration of particles that remain in the exit air stream?

Solution:

It is always helpful to start a problem off by drawing a diagram and labeling the known/given quantities. The diagram for this problem would be:



In order to determine the concentration of particles that are collected, we must recall the definition of efficiency in terms of the concentrations of particles that are at the inlet and those that are collected within the system (C_{inlet} and $C_{collected}$, respectively) :

$$\eta = \frac{C_{collected}}{C_{inlet}} \text{ x } 100$$

Thus,

$$98\% = \frac{C_{collected}}{100 \mu g\, m^{-3}} \text{ x } 100$$

Rearranging this last expression and solving for the concentration of particles collected in the system gives $C_{collected}$= 98 μg/m^3. If we start with 100 μg/m^3 and 98 μg/m^3 are collected, then we must have 2 μg/m^3 at the exit of the collector.

Solution: Problem #3

Problem Statement:

A particle laden air stream contains 100 μg particles/m^3 of air. If the particle concentration is to be reduced to 2 μg/m^3 using particle collectors, how many collectors must be used? Assume that (a) the collectors are placed in series, (b) each collector is identical, and (c) each collector has a collection efficiency of 75%.

Solution:

We know that the basic definition of efficiency is:

$$\eta = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \text{ x } 100$$

$$\eta = \frac{C_{collected}}{C_{inlet}} \text{ x } 100.$$

This definition of efficiency is the same irrespective of whether one collector or multiple collectors placed in series are used.

If we assume that we have two collectors, the inlet concentration to the first collector (C_{inlet}) is "y", and each collector has an efficiency (η_i), then we can draw a diagram (seen on the next page) for two collectors in series, each with an efficiency of 75%.

If this example is extended to N collectors, then the concentration at the outlet of the Nth collector is $y(1-\eta_\iota)^N$. The efficiency of collection for the overall system is:

$$\eta_{overall} = \frac{y - y(1-\eta_i)^{N}{}_{t}}{y} \times 100 = 1 - (1-\eta_i)^N$$

Solving this last expression for the number of collectors, N, gives:

$$N = \frac{\ell n(1-\eta_{overall})}{\ell n(1-\eta_i)}$$

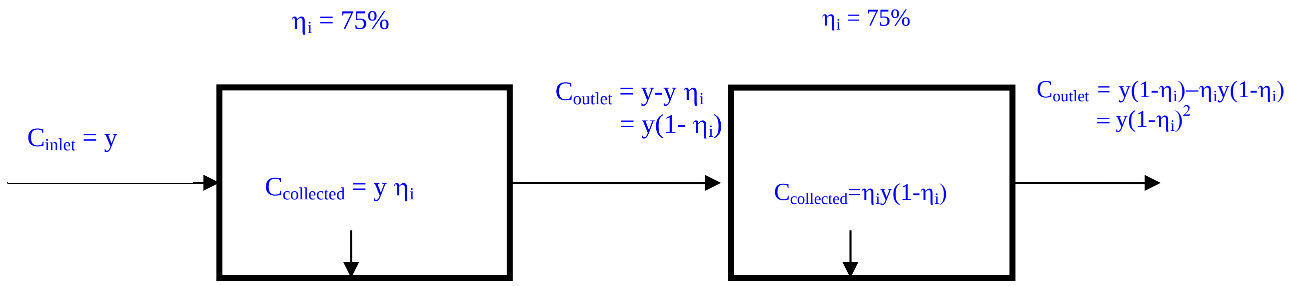
If the inlet concentration is 100 μg/m^3, and the outlet concentration is 2 μg/m^3, then the overall efficiency is:

$$\eta_{overall} = \frac{(100-2)\mu g\, m^{-3}}{100\mu g\, m^{-3}} * 100 = 98\%$$

Using this overall efficiency and the efficiency of each collector in the expression for the number of collectors, N, that are needed gives:

$$N = \frac{\ell n(1-0.98)}{\ell n(1-0.75)} = 2.82$$

Since we cannot have a fraction of a collector, we must use 3 collectors.


η_i = 75%
η_i = 75%
$C_{inlet} = y$
$C_{collected} = y\ \eta_i$
$C_{outlet} = y - y\ \eta_i$
$= y(1 - \eta_i)$
$C_{collected} = \eta_i y(1-\eta_i)$
$C_{outlet} = y(1-\eta_i) - \eta_i y(1-\eta_i)$
$= y(1-\eta_i)^2$