SEPERATION OF PARTICLES FROM AIR BY USING A SETTLING CHAMBER

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Sciencein Chemical Engineering

by
AHMAD SHAMIL Abd Al-RAHMAN Al-BAZAZ
(B.Sc. in Chemical Engineering 2001)

Shaaban 1425
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CERTIFICATION

I certify that this thesis entitled ***"Separation of Particles from Air by Using a Settling Chamber"*** was prepared by **Ahmad Shamil Abd Al-Rahman Al-Bazaz**, under my supervision at AL-Nahrain University, College of Engineering, in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering.

Signature: Latif

Dr. Mohammad N. Latif

Date: 30 / 11 / 2004

Signature:

Prof. Dr. Qasim J. Slaiman

Head of Chemical Engineering Department

Date: 7 / 12 / 2004

CERTIFICATE

We certify that we have read this thesis, entitled ***"Separation of Particles from Air by Using a Settling Chamber"*** and as examining committee examined the student **Ahmad Shamil Abd Al-Rahman Al-Bazaz** in its content, and that in our opinion it is adequate for the partial fulfillment of requirements for the degree of Master of Science in Chemical Engineering.

Signature:
Dr. Mohammad N. Latif
(Supervisor)
Date: 30 / 11 / 2004

Signature:
Dr. Muhanned A.R. Mohammed
(Member)
Date: 30 / 11 / 2004

Signature:
Dr. Shahrazad R. Rauf
(Member)
Date: 29 / 11 / 2004

Signature: J. Shanshool
Prof. Dr. Jabir Shanshool
(Chairman)
Date : 30 / 11 / 04

Approval of the College of Engineering

Signature:
Prof. Dr. Fawzi M. AL-Naima
Dean of the collage of engineering
Date: 20 / 12 / 2004

Abstract

An equation for determining the distance that a suspended dust particle in the gas (taken as air) needs to settle has been obtained as a function of height of the chamber, velocity of the air, and diameter of the dust particle.

This traveling distance by a particle with certain diameter also represents the maximum length of the chamber which the same particle will settle in, particles with larger diameters will settle out of the chamber, whereas particles with smaller diameters will settle in the chamber.

The chamber, here, was assumed to be an infinite length chamber without walls to limit it; the control would be made on the height of the entrance of particles and the velocity of the gas which the two would be assumed.

In general, the factors that make the length of the chamber effects are height of the chamber, velocity of the gas, and settling velocity, thus studying the effects of these factors is important for obtaining the length's equation.

The studying is simplified by either taking different assumed values of height of the chamber with constant assumed value of velocity of the gas, or taking different assumed values of velocity of the gas with constant assumed value of height of the chamber, whereas different values of settling velocity have been obtained by substituting assumed diameters in certain equations that determine the settling velocity, as a result different values of length of the chamber have been obtained in the two cases, and that done by software program.

These different values of length have been represented using software program by two equations each according to its case. The average errors of the constant gas velocity equation and constant height of the chamber equation are 5 % and 4.9 % respectively.

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List of Symbols

Symbol	Definition	Unit
A_p	Projected area of particle.	m^2
Ar	Archimedes number.	dimensionless
a_e	Acceleration of particle from external force.	m/s^2
a,H	Height of the chamber.	m
b,W	Width of the chamber.	m
b_1	Constant in equation (3-19).	
C_D	Drag coefficient.	dimensionless
D_p	Diameter of the particle.	m
F_e	External force.	N
F_b	Buoyant force.	N
F_D	Total drag force.	N
g	Gravitational acceleration.	m/s^2
$H(x)$	Distribution function.	
k	Parameter in equation (3-36).	
L	Length of the chamber.	m
Ly	Lyashenko number.	dimensionless
m	Mass.	kg
n	Constant in equation (3-19), parameter in equation (3-35).	
$N_{Re,p}$	Particle Reynolds number.	dimensionless
S	Area of the chamber.	m^2
t	Time.	s
u	Fluid velocity.	m/s
u_t	Terminal settling velocity of particle.	m/s

u_o	Approaching stream velocity.	m/s
V	Volume.	m^3
V_s	Settling velocity.	m/s
V_g	Gas velocity.	m/s
x	Diameter.	m
ρ_p	Density of the particle.	kg/m^3
$\rho_{f,}$ ρ	Density of the fluid.	kg/m^3
μ	Absolute viscosity.	kg/m.s
υ	Kinematics viscosity.	m^2/s
σ	Standard deviation.	
α	Factor in equation (3-38).	
β	Factor in equation (3-37).	

Chapter One

Introduction

1.1 Introduction

The necessity for removing suspended dust and mist from a gas arises not only in the treatment of effluent gas from works before it is discharged into the atmosphere, but also in processes where solids or liquids are carried over in the vapor or gas stream. Thus, in an evaporator it is frequently necessary to eliminate droplets which become entrained in the vapor, and in a plant involving a fluidized solid the removal of fine particles is necessary, firstly, to prevent loss of material, and secondly to prevent contamination of the gaseous product. Further, in all pneumatic conveying plants, some form of separator must be provided at the downstream end [1].

In general, gas must be cleaned from dust for one or more of three purposes [2]:

1) The dust contained in the gas may be valuable as, for example, when it is the product from a process.
2) The gas itself may be required for use in a further process as, for example, blast-furnace gas used for firing stoves.

3) It may be an effluent which must be cleaned before discharge into the atmosphere to avoid nuisance or damage to amenities.

Gas cleaning can be a very expensive process, particularly if almost complete removal of all of the dust is required, and great care must be given to the selection of the most economic equipment for a particular purpose bearing in mind capital charges and running costs, and possible returns on the process .It is necessary, therefore, to have an adequate knowledge of the principal features and fields of application of the various types of gas cleaning equipment available. It is clearly necessary to ensure that any dust arrestment plant is properly constructed and is, in fact, a satisfactory engineering design. What is equally important, however, is that the dust arrestment efficiency of the plant should conform to the design and it is here that the most costly errors are likely to be made if full data on the behavior of the dusts involved are not available [2].

The choice of collection equipment for a specific purpose depends upon a number of factors [3]:

a) The properties of the material, such as particle size, and physical and chemical properties;
b) The concentration and volume of the particulate to be handled;
c) The temperature and humidity of the gaseous medium and, most importantly, the collection efficiency required.

There are six types of collectors [3]:

1) Gravitational settling chambers;
2) Centrifugal separators;

3) Wet scrubbers;
4) Filters;
5) Electrostatic precipitators;
6) Ultrasonic agglomerators.

The mechanisms by which particles are collected depend upon the particle size and velocity [3].

From these six types the first one will be taken, gravity settling chambers are the oldest and simplest means of removing suspended particles from a gas. In principle, pollutants are removed by reducing the velocity of the gas stream sufficiently to allow particles to settle out. The simplest chamber is merely a horizontal duct in which large particle settle out on the floor [4].

The aim of this research is firstly, to get an equation for determining the distance that a dust particle needs to settle as a function of the diameter, velocity of the gas, and the height of the chamber, And secondly, to get an equation for the displacement in terms of the statistical distributions for powders with studying the influence of certain parameters exist in the distribution equation on the equation of the distance which also considers equation of the length of the chamber.

Chapter Two

Literature Survey

2.1 Control of Particulate

Particulates are defined as solids, fumes, liquid drops, or mists that can remain suspended in air. Typical particle sizes range from 0.1 microns to 100 microns in diameter. The human eye can see particles 10 microns and above. Mechanical collectors like settling chambers and cyclones are used for larger particulate matter (more than 50 μm). For particulates less than 5 microns, additional equipment must be used, such as the electrostatic precipitator, fabric filter, or venturi scrubber. Costs tend to increase for high efficiency collection of fine particulate [5]. Fine particulates in the atmosphere follow the normal-log distribution [6]. A typical distribution of fine particulate in the atmosphere is given in Table 2-1 and illustrated in Figure 2-1.

Table 2-1 Typical Distribution of Fine Particles in the Atmosphere [7].

Frequency	Diameter range (μm)
1	1
1	1 - 1.2

3	**1.2 - 1.6**
4.5	**1.6 - 2.0**
27.5	**2 - 4**
23	**4 - 6**
15	**6 - 8**
9	**8 - 10**
5.6	**10 - 12**

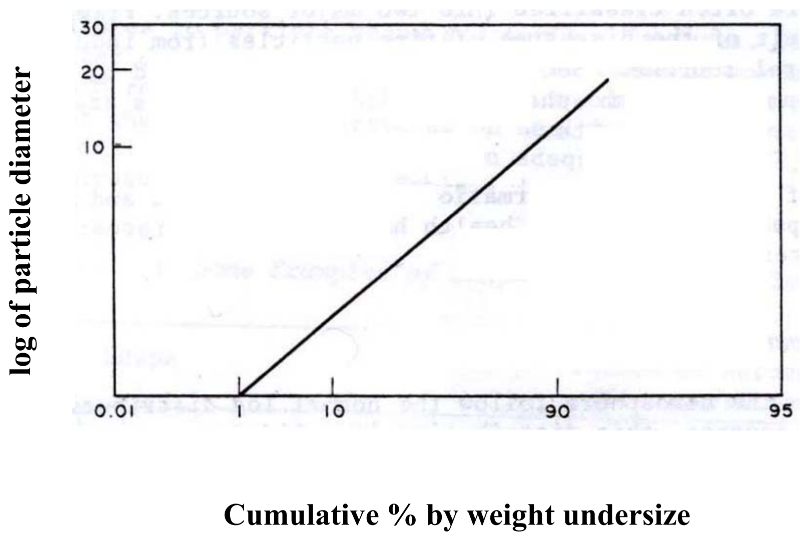

Figure 2-1 A Typical Distribution Plotted on Function Coordinates.

2.2 Particle Classification

Much confusion exists among engineers with respect to the terminology related to particle classification. Before selecting or sizing a specific control device, a careful evaluation of all aspects of the process and contaminants must be made. Improper terminology can lead to poor design and/or operation of any type of device. A list of contaminant definitions in according with the USA standards institute includes the following.

2.2.1 Liquid in Gas

Mists and Sprays*:* There are numerous industrial chemical operations which involve liquid-in-gas dispersion. These operations generate mists and sprays that consist of particles in diameter ranges of 0.1 to 5,000 μm. Engineers most commonly encounter spray droplets which are particles often formed unintentionally in chemical plant operations. For example, vapors or fumes may condense on piping, ducts, or stack walls. Under such conditions liquid films are form.

2.2.2 Solid in Gas

Dusts: Dusts are fine solid particles often formed in such operations as crushing, grinding, drilling, detonation, and polishing. Other industrial sources are conveying operations and screening. Particle diameters generally are in the range of 1.0 to 1,000 μm. Dusts generally do not diffuse in air, but settle out by gravity.

Fly ash: Fly ashes are finely divided matter generally entrained in flue gases that arise from combustion. Particles range from 1 μm in size on down. This is not within the operational range of gravity settling chambers. Wet scrubbers are generally employed in fly ash control.

Fumes: Fumes are finely divided solid particles that are generated by the condensation of vapors. Fumes are generally the by-products of sublimation, distillation, and molten metal processes. Particles diameter are generally in the range of 0.1 to 1 μm.

Smoke: smoke constitutes fine, solid, gas borne matters that are products of incomplete combustion of organics wood, coal, tobacco. Smoke particles are extremely small, ranging in size from less than 0.01 μm to 1μm. Smog refers to a mixture of natural fog and industrial smoke.

Aerosols: aerosols are an assemblage of small particles, either solid or liquid, suspended in gas. Particles sizes range from 0.01 to 100 μm. There are several classes of aerosols.

A) Dispersion aerosols are a common class that is formed from processes such as grinding, solid and liquid atomization. Dispersion aerosols are usually composed of individual or slightly aggregated particles irregularly formed.
B) Condensation aerosols are formed when supersaturated vapors condense. This latter class is usually less than 1mm in size. Dispersion aerosols are considerably more coarse and contain a wide variety of particle sizes. Condensed aerosols usually consist of solid particles that are loose

aggregates of a large number of primary particles of crystalline or spherical shape.

The term grit is used to classify coarse particles that are unable to pass through 200-mesh screen. These particles are normally greater than 43 µm in diameter and are within the operating efficiency of gravity settling chambers [4].

Particulate pollutants are divided generally into dust that settles in air and dust that remains suspended as an aerosol. The physical consideration determining into which class a particle falls is the particle diameter.

2.3 Stokes' Law

Sedimentation, the ability of particles to settle, is defined by a relationship that involves the terminal settling velocity of particles falling under the influence of gravity. This relationship, called Stokes' law.
The velocity of the particles in the settling chamber can be obtained by Stokes' law.

Assuming that the particles are spherical and that a constant buoyancy is exerted by air, then

$$V_s = \frac{g D_p^{\,2} \left(\rho_p - \rho_f\right)}{18\mu} \qquad \dots (2\text{-}1)$$

Where μ = viscosity of fluid

ρ_p = density of particle

ρ_f = density of fluid

g = acceleration due to gravity

Solving this equation for the settling rates of particles gives the results over a range of diameters shown in Table 2-2.

Table 2-2 Settling Rates of Various Particles at 18°C [8].

Particle diameter (μm)	Terminal settling velocity (ft/hr)
0.01	**0.000036**
1.0	**0.36**
5.0	**9.24**
10.0	**36.0**

From the data in Table 2-2, it is obvious that the actual settling ability of very small particles approaching molecular diameter is so small that, for practical purpose, such particles remain suspended in air and are even difficult to remove by air washing as occurs with rainfall.

As a matter of working definition, particles larger than 10 μm diameter are usually thought of as "settle able" while those of a smaller diameter are referred to as "suspended" [8].

Table 2-3 Time for Particles to Fall 1 km by Sedimentation [9].

Diameter (μm)	**Time to fall (1 Km)**
0.02	**228 yr**
0.1	**36 yr**
0.5	**3.2 yr**
1	**328 days**
5	**14.5 days**
10	**3.6 days**
20	**23 h**
100	**1.1 h**
1000	**4 min**

Stokes' law cannot be applied indiscriminately to all particles settling in a fluid. In the strictest theoretical sense, it is only valid under the following conditions and limitations.

1. Particles must have reached terminal fall velocity. For particles within the size range of applicability of stokes' law, the terminal fall velocity is reached almost instantaneously. Weyssenhoff 1920 has shown that for a sphere with a diameter of 50μm, the terminal fall velocity is reached in about 0.003 second. For smaller particles, the time is even less [10].
2. Particles must be rigid. All particles analyzed sedimentologically fulfill this condition.

3. Particles must be smooth. Most particles analyzed sedimentologically are not smooth. Arnold 1911 has shown that within the size range of applicability of stokes' law, grains with irregular surfaces do not have any appreciable difference in settling velocity from smooth grains and the theoretical condition has no practical validity [11] .
4. No slippage or shear may take place between the particle and the fluid. This depends on the wettability of the particle in the fluid, and the condition is fulfilled when water is used as the fluid.
5. The fluid must be of infinite extent in relation to the particles. A particle settling near the wall of a container will have its settling velocity decreased by an amount dependent on the nearness of the wall and the size of the particle. In the size range of stokes' law, the wall effects are negligible if the sedimentation vessel is greater than 4 cm in diameter. Most 1000 ml graduated cylinders used in the pipette analyses of silt and clay are larger than this[12].
6. Particle concentration must be less than 1%. If particle concentration is high, the individual particles will interfere with one another during settling and the actual viscosity of the fluid will be different from that of the pure fluid. The maximum allowable concentration depends on the viscosity of the fluid, the particle size, the range in particle size, and the particle shape. For quartz particles which are within the range of applicability of stokes' law and which are settling in distilled water, the particle concentration should not exceed about 1% by volume [13]. This means a maximum of about 25 gm of sample can be used in a 1000 ml cylinder for a pipette analysis. Better results are more consistently obtained if the sample is about 10 gm a concentration of about 0.4%.

7. Particles must be greater than 0.5µm in diameter. Very small particles are affected by the Brownian movement of the molecules of the fluid. This keeps the particles from falling in a straight line, and consequently the resistance to fall is no longer only a function of the particle size and the viscosity of the fluid. Krumbein and Pettijohn 1938 report that Stokes' law holds down to 0.1µm. Later reports e.g., Irani and Callis, 1963 suggested that the law is valid only down to 0.5µm under ordinary settling conditions. If, however, centrifugal sedimentation is used, a modification of the law is valid down to 0.1µm [12, 13].
8. Particles must not be greater than 50µm in diameter. The upper limit to the size of particles settling according to Stokes' law is a function of the temperature and Reynold's Number of the fluid and the density of the particles. Above this limit there is turbulence during settling. Oseen 1913 determined that Stokes' law is theoretically valid only up to 50µm. However, Ruby 1933 has shown that observed settling velocity differs little from the theoretically determined Stokes' values up to about 140µm. Most investigators use Stokes' law up to the lower size limit of sand, 62.5µm, realizing that there may be a slight error in the 50 to 62.5µm fraction [14, 15].
9. Particles must be spheres. In nature, practically no particles are perfect spheres. Wadell 1934, using the same basic assumptions as stokes, developed a settling velocity formula that takes particle shape into consideration. Wadell used a particle shape between that of a sphere and a disk which is much closer to the average shape in nature than is a sphere. In essence, Wadell's formula reduces the settling velocity determined by

stokes' law. To convert any Stokes' value to a Wadell value, multiply by 0.64 [16].

2.4 Gravity Settling Chamber

Settling chambers, which rely on gravitational settling as a collection mechanism, are the simplest and oldest mechanical collectors. Settling chambers are generally built in the form of long, horizontal, rectangular chambers with an inlet at one end and an exit at the side or top of the opposite end [17, 18, 19, 20, 21, 22, and 23].

So it is a long duct fitted with hoppers on the floor to collect particulates. Physical dimensions are characterized by the ductwork above the collection hoppers as shown in Figure 2-1.

Length = L, width = W, and height = H.

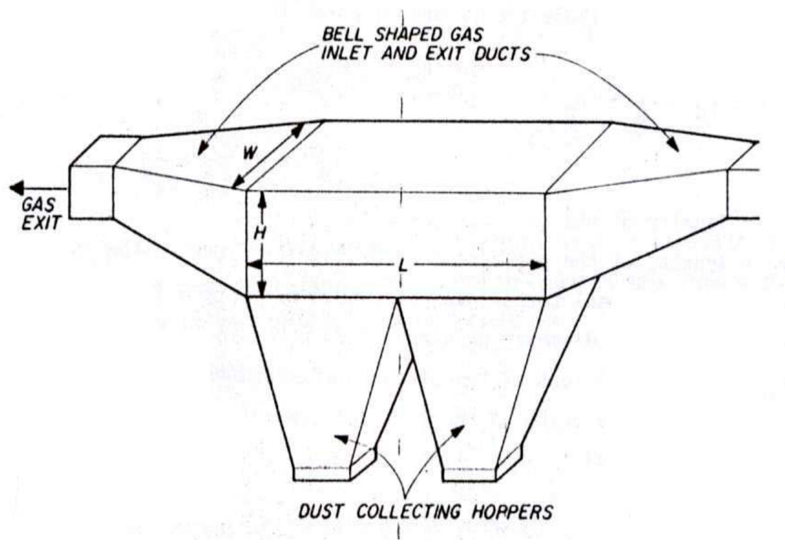

Figure 2-1 Gravity Settling Chamber.

The primary section of the chamber is characterized by its cross-sectional area WH and by its length L. The cross-sectional area is designed to be larger than the inlet and exit ducts in order to reduce substantially the gas stream's linear velocity. So that the gas velocity inside is much lower than in either of those two ducts. The length of the chamber determines the amount of time the particles remain at the reduced rate. This starving of the gas's forward motion allows the particles sufficient time to settle out into the hoppers [4].

Hoppers are used to collect the settled-out materials, though drag scrapers and screw conveyers have also been employed. The dust removal system must be sealed to prevent air from leaking into the chamber which increases turbulence; causes dust re entrainment, and prevent dust from being properly discharged from the device.

Flow within the chamber must be uniform and without any macroscopic mixing. Uniform flow is often ensured by flow straighteners at the inlet to the chamber [17, 18, 19, 20, 21, 22, and 23].

There are two primary types of settling chambers: the expansion chamber and the multiple-tray chamber. In the expansion chamber, the velocity of the gas stream is significantly reduced as the gas expands in a large chamber. The reduction in velocity allows larger particles to settle out of the gas stream [17, 18, 20, 21, and 23].

A multiple-tray settling chamber is an expansion chamber with a number of thin trays closely spaced within the chamber, which causes the gas to flow horizontally between them. While the gas velocity is increased slightly in a multiple-tray chamber, when compared to a simple expansion chamber, the collection efficiency generally improves because the particles have much shorter distance to fall before they are collected. Multiple-tray settling chambers have lower volume requirements than expansion-type settling chambers for the collection of small particles > 15 µm [23].

The efficiency of settling chambers increases with residence time of the waste gas in the chamber. Because of this, settling chambers are often operated at the lowest possible gas velocities. In reality, the gas velocity must be low enough to prevent dust form becoming re entrained, but not so low that the chamber becomes unreasonably large. The size of the unit is generally driven by the desired gas velocity within the unit, which should be less than 3 meters per second m/s, and preferably less than 0.3 m/s [18, 19, 21, and 23].

High-efficiency settling chambers are often fitted with baffles or deflectors to change the gas flow direction. The device is primarily effective for removal of coarse particles, called grit, thus limiting its industrial utility to that of a precleaning device, ahead of a more efficient collector [4].

Settling chambers have been used extensively in the past. The metals refining industries have used settling chambers to collect large particles, such as arsenic trioxide from the smelting of arsenical copper ores. Power and heating plants have used settling chambers to collect large unburned carbon particles for re injection into the boiler. They are particularly useful for industries that also need to cool the gas stream prior to treatment in fabric filter [21].

Settling chambers have been used to prevent excessive abrasion and dust loading in primary collection devices by removing large particles from the gas stream, such as either very high dust loading or extremely coarse particles which might damage a downstream collector in series with the settling chamber. The upstream use of settling chambers has declined with improvements in acceptable loading of other, more efficient, control devices and increasing space restrictions at facilities. In cases where sparks or heated material is present in the waste gas, settling chambers are still used to serve as "spark traps" to prevent a downstream bag house or filter from catching fire [18, 23, 24, and 25].

These devices are generally constructed for a specific application from duct materials, though almost any material can be used. Settling chambers have been replaced, for most applications, by cyclones primarily due to the lower space requirements and the higher collection efficiency of cyclones. Multiple-tray settling chambers have never been widely used because of the difficulty in removing the settled dust from the horizontal trays [21, 24].

The collection efficiency of settling chambers varies as a function of particle size and settling chamber design. Settling chambers are most effective for large and/or dense particles. Gravitational force may be employed to remove particles where the settling velocity is greater than about 13 centimeters per second cm/s. In general, this applies to particles larger than 50 µm if the particle density is low, down to 10 µm if the material density is reasonably high. Particles smaller than this would require excessive horizontal flow distances, which would lead to excessive chamber volumes [18, 21, 23].

2.4.1 Advantages

Advantages of settling chambers include [18, 19, 20, 21, 23, and 26]:

1) Low capital cost;
2) Very low energy cost;
3) Simple construction;
4) No moving parts, therefore, few maintenance requirements and low operating costs;
5) Excellent reliability;
6) Low pressure drop through device;
7) Device not subject to abrasion due to low gas velocity;
8) Use of any material for construction;
9) Provide incidental cooling of gas stream;
10) Temperature and pressure limitations are only dependent on the materials of construction; and
11) Dry collection and disposal.

2.4.2 Disadvantages

Disadvantages of settling chambers include [18, 21, and 23]:

1) Relatively low PM collection efficiencies, particularly for PM less than 50 μm in size;
2) Unable to handle sticky or tacky materials;
3) Large physical size; and

4) Trays in multiple-tray settling chamber may wrap during high-temperature operations.

Because of the above advantages and disadvantages, settling chambers are mostly used as pre-cleaners. They are sometimes used in the process industries. Particularly in the food and metallurgical industries as the first step in dust control, Use of settling chambers as pre-cleaners can also reduce the maintenance cost of high efficiency control equipment, which is more subject to abrasive deterioration [26].

Chapter Three

Theory of Operation

3.1 Motion of Particles Through Fluids

Many processing steps, especially mechanical separations, involve the movement of solid particles or liquid drops through a fluid. The fluid may be gas or liquid, and it may be flowing or at rest. Examples are the elimination of dust and fumes from air or flue gas, the removal of solids from liquid wastes to allow discharge into public drainage systems, and the recovery of acid mists from the waste gas of an acid plant [27].

3.1.1 Mechanics of Particle Motion

The movement of a particle through a fluid requires that a density difference exists between the particles and the fluid. Also, an external force is needed to impart motion to the particle relative to the fluid. The external force is usually gravity, but when gravity is not sufficiently strong, centrifugal force, which can be many times that of gravity, is used. If the densities of particle and fluid are equal, the buoyant force from the immersion of the particle in the fluid will counterbalance an external force, however large, and the particle will not move through the fluid. The greater the density difference, the more effective the process [27].

Three forces act on a particle moving through a fluid [27]:

1. The external force, gravitational or centrifugal;
2. The buoyant force, which acts parallel with the external force, but in the opposite direction; and
3. The drag force, which appears whenever there is relative motion between the particle and the fluid. The drag force acts to oppose the motion and acts parallel with the direction of movement but in the opposite direction.

3.1.2 Equations for One-Dimensional Motion of Particle Through Fluid

Consider a particle of mass m (Kg) moving through a fluid under the action of an external force F_e (N). Let the velocity of the particle relative to the fluid be u (m/s). Let the buoyant force on the particle be F_b (N), and let the drag be F_D (N). Then, the resultant force on the particle is F_e - F_b - F_D, the acceleration of the particle is $\frac{du}{dt}$ (m/sec^2), and according to the Newton's law

$$m \frac{du}{dt} = F_e - F_b - F_D \qquad \text{… (3-1)}$$

The external force can be expressed as a product of the mass and the acceleration a_e of the particle from this force, and

$$F_e = ma_e \qquad \text{… (3-2)}$$

The buoyant force is, by Archimedes's principle, the product of the mass of the fluid displaced by the particle and the acceleration from the external force. The volume of the particle is m/ρ_p (m^3), where ρ_p the density of the particle, and the particle displaces this same volume of fluid. The mass of fluid displaced is $(m/\rho_p)\rho$ (Kg), where ρ is the density of the fluid. The buoyant force is, then

$$F_b = \frac{m \rho a_e}{\rho_p} \quad \text{… (3-3)}$$

The drag force is,

$$F_D = \frac{C_D u_\circ^2 \rho A_p}{2} \quad \text{… (3-4)}$$

Where C_D is the dimensionless drag coefficient and A_p is the projected area, in square meter, of the particle measured in a plane perpendicular to the direction of motion of the particle. Also $u_o = u$ [27].

Substituting the forces from equations (3-2) through (3-4) into equation (3-1) gives

$$\frac{du}{dt} = a_e - \frac{\rho a_e}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m}$$

$$= a_e \frac{\rho_p - \rho}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m} \quad \text{… (3-5)}$$

3.1.3 Motion from Gravitational Force

If the external force is gravity, a_e is g, the acceleration of gravity in meter per second square, and equation (3-5) becomes [27].

$$\frac{du}{dt} = g\,\frac{\rho_p - \rho}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m} \qquad \ldots (3\text{-}6)$$

3.1.4 Terminal Velocity

In gravitational settling, g is constant. Also, the drag always increases with velocity. Equation (3-6) shows that the acceleration decreases with time and approaches zero. The particle quickly reaches a constant velocity, which is the maximum attainable under the circumstances, and which is called the terminal velocity. The equation for the terminal velocity u_t is found, for gravitational settling by taking $\frac{du}{dt} = 0$. Then, from equation (3-6),

$$u_t = \sqrt{\frac{2g(\rho_p - \rho)m}{A_p \rho_p C_D \rho}} \qquad \ldots (3\text{-}7)$$

3.1.5 Drag Coefficients

The quantitative use of equations (3-5) to (3-7) requires that numerical values be available for the drag coefficients C_D.
A portion of the curve of C_D vs. N_{Re} for spheres is shown in Figure 3-1.

The drag curve shown in Figure 3-1 applies, however, only under restricted condition. The particle must be a solid sphere; it must be free to move without being influenced by other particles or by the wall or bottom of the vessel, it must be moving at a constant velocity, it must not be too small, and the fluid through which it is moving must be still [27].

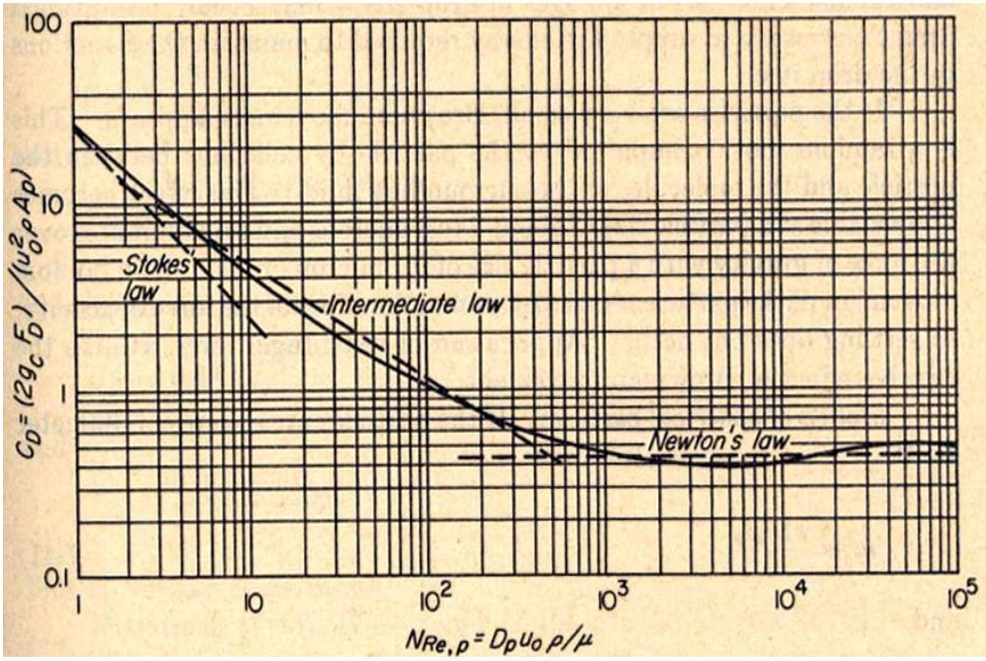

Figure 3-1 Drag Coefficients for Spheres.

3.1.6 Motion of Spherical Particles

If the particles are spheres of diameter D_p (m),

$$m = \frac{\pi D_p^{\,3} \rho_p}{6} \qquad \ldots (3\text{-}8)$$

And

$$A_p = \frac{\pi D_p^2}{4} \qquad \text{… (3-9)}$$

Substitution of m and A_p from equations (3-8) and (3-9) into equation (3-5) gives [27].

$$\frac{du}{dt} = a_e \frac{\rho_p - \rho}{\rho_p} - \frac{3C_D u^2 \rho}{4\rho_p D_p} \qquad \text{… (3-10)}$$

At the terminal velocity, $\frac{du}{dt} = 0,$ and

$$a_e\left(\rho_p - \rho\right) = \frac{3C_D u_t^2 \rho}{4D_p} \qquad \text{… (3-11)}$$

$$u_t = \sqrt{\frac{4a_e D_p\left(\rho_p - \rho\right)}{3C_D \rho}} \qquad \text{… (3-12)}$$

3.1.7 Approximate Equations for Drag Coefficients of Spheres

In Figure 3-1 the continuous curve, can be replaced by three straight lines without serious loss in accuracy. These lines, each of which covers a definite range of Reynolds numbers, are shown as dotted lines in Figure 3-1. The equations for the lines and the ranges of the Reynolds number over which each applies are, for $N_{Re} < 2$,

$$C_D = \frac{24}{N_{\mathrm{Re},p}} \qquad \text{… (3-13)}$$

And

$$F_D = 3\pi\mu u_t D_p \qquad \text{… (3-14)}$$

This is the Stokes'-law range. For $2 < N_{Re,\,p} < 500$, the equations are,

$$C_D = \frac{18.5}{N_{\mathrm{Re},p}^{\;0.6}} \qquad \text{… (3-15)}$$

And

$$F_D = 2.31\pi\left(u_t D_p\right)^{1.4} \mu^{0.6} \rho^{0.4} \qquad \text{… (3-16)}$$

This is the intermediate range. For $500 < N_{Re,\,p} < 200{,}000$,

$$C_D = 0.44 \qquad \text{… (3-17)}$$

And

$$F_D = 0.055\pi\left(u_t D_p\right)^2 \rho \qquad \text{… (3-18)}$$

This is Newton's-law range.

Equations (3-13), (3-15), and (3-17) can be written in the single general form

$$C_D = \frac{b_1}{N_{\mathrm{Re},p}^{\;n}} \qquad \text{… (3-19)}$$

Then equations (3-14), (3-16), and (3-18) all can be written as

$$F_D = \frac{\mu^n b_1 \pi \left(D_p u_t\right)^{2-n} \rho^{1-n}}{8} \qquad \text{… (3-20)}$$

Where b_1 and n are constants, summarized in Table 3-1

Table 3-1 Constants in Equations for Drag Coefficients [27].

Range	b_1	n
Stokes-law	**24**	**1**
Intermediate	**18.5**	**0.6**
Newton's-law	**0.44**	**0**

A general equation for the terminal velocity of spheres is obtained by substituting C_D from equation (3-19) into equation (3-11) and solving for u_t [27].

$$a_e\left(\rho_p - \rho\right) = \frac{3u_t^2 b_1 \rho \mu^n}{4D_p \left(D_p u_t \rho\right)^n} \qquad \text{… (3-21)}$$

And

$$u_t = \left[\frac{4a_e D_p^{1+n}\left(\rho_p - \rho\right)}{3b_1 \mu^n \rho^{1-n}}\right]^{1/(2-n)} \qquad \text{… (3-22)}$$

For gravity settling $a_e = g$, and for Stokes' law range $N_{Re} < 2$, equation (3-22) becomes

$$u_t = \frac{g D_p{}^2 \left(\rho_p - \rho\right)}{18\mu} \qquad \text{… (3-23)}$$

For intermediate range $2 < N_{Re,\,p} < 500$,

$$u_t = \frac{0.153 a_e{}^{0.71} D_p{}^{1.14} \left(\rho_p - \rho\right)^{0.71}}{\rho^{0.29} \mu^{0.43}} \qquad \text{… (3-24)}$$

And for Newton's-law range $500 < N_{Re,\,p} < 200{,}000$,

$$u_t = 1.74 \sqrt{\frac{a_e D_p \left(\rho_p - \rho\right)}{\rho}} \qquad \text{… (3-25)}$$

3.2 Definitions Using in Modeling

In a dust chamber or a horizontal flue, a dust particle falls at a velocity $w_f = V_s$ under the action of gravity and the resistance offered by the gas and also travels along the length of the chamber at a velocity equal to that of the gas stream $w_g = V_g$ see Figure 3-2 [28].

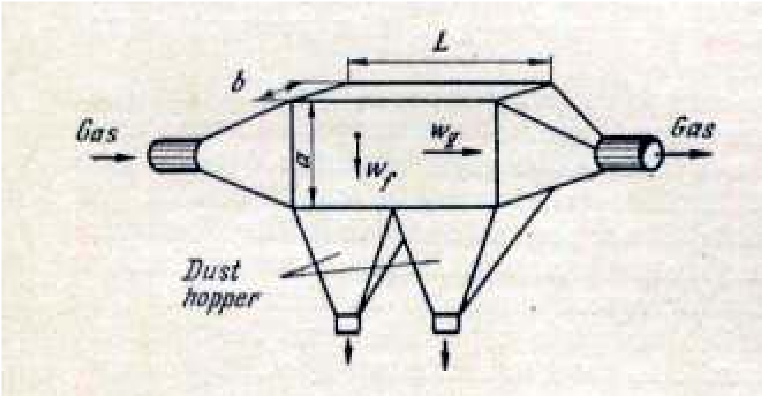

Figure 3-2 Schematic Diagram of a Dust Chamber.

For a dust particle to settle, it must reach the bottom of the chamber before the gas stream carries it away.

The longest path is that of a dust particle entering the chamber at the top. In a chamber of height *a* see Figure 3-2, the time taken by a particle at the top of the chamber to fall is

$$t = \frac{a}{V_s} \qquad \text{… (3-26)}$$

At the same time, with the length of a chamber and the horizontal velocity of a stream being respectively *L* and V_g, the residence time of the gas in the chamber is

$$t_{residence} = \frac{L}{V_g} \qquad \text{… (3-27)}$$

It follows then that the particle initially located at the top will be deposited in the chamber if its time of fall will not exceed the residence time of the gas in the chamber, i.e.

$$\frac{a}{V_s} = \frac{L}{V_g} \qquad \ldots (3\text{-}28)$$

And from equation (3-28)

$$L = \frac{aV_g}{V_s} \qquad \ldots (3\text{-}29)$$

Let V be the volume of the gas (m^3) passing through the chamber per second, and b, the width of the chamber. Then the mean gas velocity in the chamber is

$$V_g = \frac{V}{ab} \qquad \ldots (3\text{-}30)$$

Substituting this value of V_g into equation (3-28), we obtain

$$\frac{a}{V_s} = \frac{Lab}{V} \qquad \text{Or} \qquad Lb = \frac{V}{V_s}$$

Note that the product Lb is the area of the chamber. Designating this area by S, we obtain

$$V = SV_s \qquad \ldots (3\text{-}31)$$

3.2.1 Archimedes Number

Archimedes number is a dimensionless number which equals to the multiplication of the cubic diameter, gravitational acceleration, and the difference between the particle and the fluid density divided by the multiplication of the square kinematics viscosity and the fluid density.

$$Ar = \frac{D_p^3 g}{\upsilon^2} \frac{\left(\rho_p - \rho_f\right)}{\rho_f} \quad \ldots (3\text{-}32)$$

D_p = Particle Diameter

g = Gravitational acceleration

υ = Kinematics viscosity

ρ_p= Particle density

ρ_f= Fluid density

3.2.2 Lyashenko Number

Lyashenko number is a dimensionless number which equals to the multiplication of the cubic settling velocity and the fluid density divided by the multiplication of the kinematics viscosity, gravitational acceleration, and the difference between the particle and the fluid density.

$$Ly = \frac{V_s^3}{\upsilon g} \frac{\rho_f}{\left(\rho_p - \rho_f\right)} \quad \ldots (3\text{-}33)$$

V_s = Settling velocity

g = Gravitational acceleration

υ = Kinematics viscosity

ρ_p= Particle density

ρ_f= Fluid density

There is a relation between Archimedes and Lyashenko number, this relation obeys to certain ranges of Archimedes number, to each range or condition there are a relation that connect Archimedes and Lyashenko number, these relations and ranges would be explained clearly in Table below:

Table 3-2 Relations Connect Dimensionless Numbers According to Certain Range [29].

Ranges of Archimedes number	**Relations connect *Ar* & *Ly* Numbers *Ly*=**
0…9	$\left(\frac{1}{18}\right)^3 Ar^2$
9…325	$(0.0815)^3 Ar^{1.5}$
325…1.07×10^4	$(0.1623)^3 Ar^{1.143}$
1.07×10^4…3×10^5	$(0.3115)^3 Ar^{0.875}$
3×10^5…3×10^9	$(1.73)^3 Ar^{1/2}$

From the equation (3-32), the Archimedes number is directly proportional to the diameter of the particle, so for giving diameter, Archimedes number is obtained, and therefore Lyashenko number is obtained by equations in Table 3-2 above each according to its range of Archimedes number.

Settling velocity then obtained by equation (3-33) for obtained Lyashenko number.

To get the displacement of the particle in equation (3-29), the height of the chamber, the gas velocity, and the falling velocity or the settling velocity should be given.

The height of the chamber and the gas velocity will be assumed, while the settling velocity will be determined from equations (3-32), (3-33), and equations in Table 3-2.

3.3 Statistical Distributions for Powders

For describing the statistical distribution of powders, there are five equations must be used for this purpose. And the equations are [29]:

1. Log-Normal distribution

$$H_r(x) = \frac{1}{\sigma_\xi \sqrt{2\pi}} \int_0^x \frac{\log e}{x} \exp\left(-\frac{\left(\log x - \log x_{50/r}\right)^2}{2\sigma_\xi^2} \right) dx \quad \ldots (3\text{-}34)$$

2. RRSB distribution (ROSIN, RAMMLER, SPERLING, and BENNETT)

$$H_3(x) = 1 - \exp\left[-\left(\frac{x}{x_{63/3}} \right)^n \right] \quad \ldots (3\text{-}35)$$

3. GGS distribution (GATES, GAUDIN, and SCHUHMANN)

$$H_3(x)=0.8\left(\frac{x}{x_{80/3}}\right)^k \qquad \ldots (3\text{-}36)$$

4. RINKES distribution

$$H_3(x)=\exp\left[-\tilde{\beta}\left(\frac{x_{\max}}{x}-1\right)\right] \qquad \ldots (3\text{-}37)$$

5. PM distribution (PREROVSKA and MISEK)

$$H_3(x)=1-\left(\frac{x^3}{6\alpha^3}+\frac{x^2}{2\alpha^2}+\frac{x}{\alpha}+1\right)\exp\left(-\frac{x}{\alpha}\right) \qquad \ldots (3\text{-}38)$$

$$H_\circ(x)=1-\exp\left(-\frac{x}{\alpha}\right)$$

Any of these five equations could be substituted in the obtained equation for the displacement of the particle. This substitution offers equation in terms of certain statistical distribution helps in determining the distance of a mixture of particles instead of one particle.

Equation (3-36) was selected for substitution, but before the substitution, equation (3-36) should simplified first and become as a function of x, which represents the diameter in the obtained equation.

$$H_3(x)=0.8\left(\frac{x}{x_{80/3}}\right)^k$$

$$\left(\frac{x}{x_{80/3}}\right)^{k} = \frac{H_3(x)}{0.8}$$

$$\frac{x}{x_{80/3}} = \left(\frac{H_3(x)}{0.8}\right)^{1/k}$$

$$x = x_{80/3}\left(\frac{H_3(x)}{0.8}\right)^{1/k} \qquad \dots (3\text{-}39)$$

Chapter Four

Results and Discussions

4.1 Introduction

In this chapter a modeling equation for the displacement of the dust particle as a function of the diameter of the particle, the height of the chamber, and the velocity of the gas (taken as air), will be derived, and an equation for the statistical distribution will be substituted in the modeling equation.

The chamber, here, was assumed to be an infinite length chamber without walls to limit it; the control would be made on the height of the entrance of particles and the velocity of the gas, which the two would be assumed. This case is applied on chimneys; so, for example, the modeling equation for the displacement could represent this particle that exits from the chimney.

Different values of the displacement of particles have been estimated by equation (3-29) which needs the height of the chamber, the velocity of the gas, that would be assumed, and the falling velocity (settling velocity) which would be estimated by using equations (3-32), (3-33), and relations in Table 3-2.

The using of these equations would be explained clearly later in section 4.2.

The estimated values of the displacement of particles have been fitted into equations that represented them. A statistical software program made the fitting.
After getting a modeling equation of the displacement as a function of the diameter, height of the chamber, and the velocity of the gas, an equation of the displacement as a function of the statistical distribution would also be obtained.

4.2 Obtaining the Displacement of the Particle by Dimensionless Numbers

For different assumed diameters, different values of Archimedes numbers have been calculated from equation (3-32), which also includes other variables such as the particle density, the fluid density, and the kinematics viscosity. Using of these variables in the equation depends upon the nature of the particle or fluid used, each has its properties. For present work, properties of the air at 25°C have been taken as illustrated in table below [30].
The particle used was dust with density equal to 2650 kg/m^3.

Fluid	Dynamic Viscosity Kg/m.s	Density Kg/m^3	Kinematics Viscosity m^2/s
Air	1.845×10^{-5}	1.2	1.54×10^{-5}

Finally, the equation also includes a gravitational acceleration, which stays constant.

There is a relation between Archimedes number and Lyashenko number.
These relations were explained in Table 3-2; each relation obeys to certain range of Archimedes number, so the relation that connects Archimedes with Lyashenko would be taken according to the calculated value of the Archimedes number from equation (3-32).

Now, when the relation has been specified, and after the substitution of Archimedes number values, different Lyashenko numbers have been obtained.

When the values of Lyashenko number has been substituted in equation (3-33) which includes variables such as the particle density, the fluid density, and the kinematics viscosity that represented given values of the properties of the material, and also includes the constant of gravitational acceleration, a settling velocity was obtained.

The displacement of the particle was defined by equation (3-29), which includes the settling velocity that has been obtained, the height of the chamber, and the velocity of the gas, which the two have been assumed.
The connection between the diameter, Archimedes number, Lyashenko number, settling velocity, and the displacement is simplifying by equations (3-32), (3-33), (3-29), and Table 3-2.

This connection with the mentioned equations has been inserted in software program, which collected all these equations that entered in the determining of the displacement Appendix A-1.

4.3 The Derivation of the Displacement Equation

To derive an equation for the displacement of the particle as a function of the diameter of the particle, the height of the chamber, and the velocity of the gas, the following steps should be taken:

1- The gas velocity was fixed on assumed constant value, and different values of height of the chamber have been taken.
2- The height of the chamber was fixed on assumed constant value, and different values of gas velocity have been taken.

In each case of the two cases above, an equation for the displacement as a function of the diameter and the height, or as a function of the diameter and the gas velocity would be obtained.

As well as this theoretical work was built upon taking one equation that would be an equation as a function of the diameter of the particle, height of the chamber, and velocity of the gas, which represented variables that entered in modeling of settling chamber, so it is obvious that the two equations would be added to each other in order to get one equation that helps in estimating the displacement of a particle knowing the diameter, height of entrance, and the gas velocity.

4.3.1 Constant Velocity of the Gas (taken as air)

The gas velocity was fixed on assumed value of 0.5 (m/s) and different values of the height have been taken. For each taken assumed value of height and fixed value of gas velocity, different values of diameter have been used. As a result, numbers of values of the displacement have been obtained facing to the same numbers of values of the diameter have been substituted, these procedures explained above have been calculated by a program Appendix A-1 which all needed equations that entered in calculations of the displacement have been inserted in it. This idea has been explained clearly in Table 4-1.

Table 4-1 The Relation Between the Diameter and the Length at Constant Gas Velocity and Different Heights.

Gas velocity = 0.5 (m/s)					
Diameter (µm)	Length (displacement) (m)				
	H=20	H=40	H=60	H=80	H=100
1	9×10^4	1.8×10^5	2.7×10^5	3.6×10^5	4.6×10^5
50	43	86	129	172	215
100	15.4	31	46	61	77
150	8.7	17	26	35	43.6
200	6.3	12.6	19	25	31.5
250	5	9.8	15	19.6	24.5
300	4	8	12	16	20
350	3.3	6.7	10	13	16.7
400	3	6	8.6	11.5	15
450	3	6	9	12	15
500	3	6	8	11	14
550	3	5	8	10	13
600	2	5	7	9	12
650	2	4	7	9	11
700	2	4	6	8	10
750	2	4	6	8	10

800	**2**	**4**	**6**	**7**	**9**
850	**2**	**3**	**5**	**7**	**9**
900	**2**	**3**	**5**	**7**	**8**

The noticed from Table 4-1that the length decreases with increasing the diameter and that reasonable, because when the particle gets larger the displacement of it will decrease and that causes an opposite relationship between the particle's diameter and the length. This relationship becomes clearly understandable when it is illustrated in Figure 4-1.

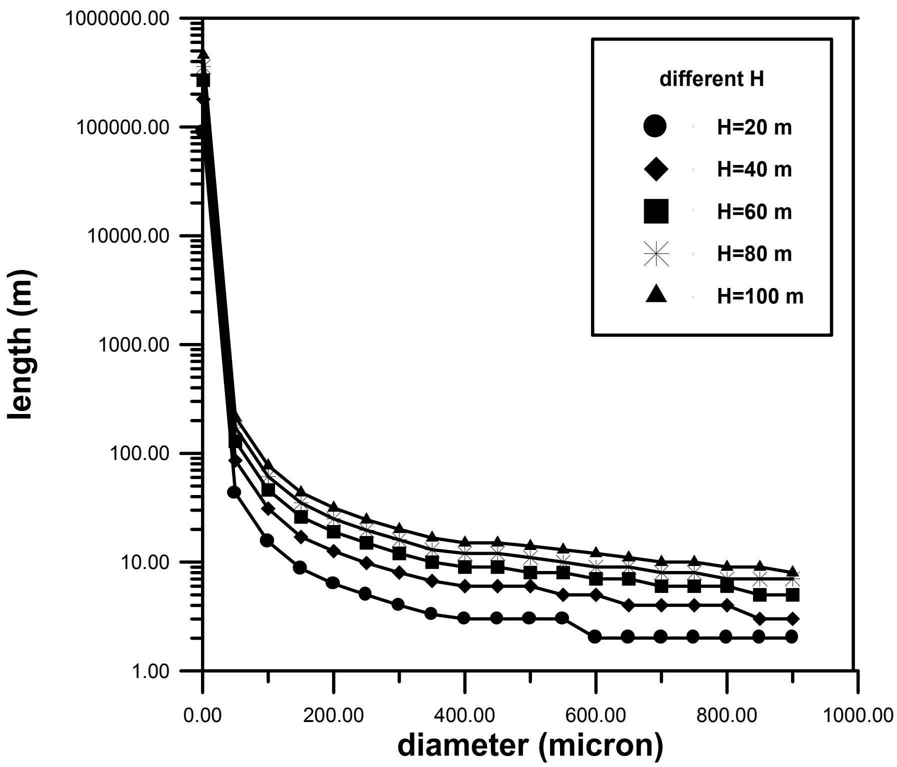

Figure 4-1 The Relation Between the Length and the Diameter at Different Values of Height.

The curves in Figure 4-1 have been represented by equation made by means of a software program in order to get an equation for the displacement as a function of the diameter. The equation is:

$$L = A + \frac{B}{D^{0.24}} + \frac{C}{D^{2}} \qquad \ldots (4\text{-}1)$$

The constants A, B, and C for the five curves when the displacement and the diameter in Table 4-1 have been substituted in equation 4-1, would be:

Table 4-2 The Different Values of Constants A, B, and C to each Value of Height.

H (m)	A	B	C
20	-4.22	29.5	89974.7
40	-9	61	179948
60	-13	90	269923
80	-18	120	359897
100	-19	136	459882.7

The constants B and C are increasing with increasing the height. So it is obvious that the relation is directly proportional and a straight line relation is taken place, while constant A takes an opposite relation with the height, as it is illustrated in Figures 4-2, 4-3, 4-4.

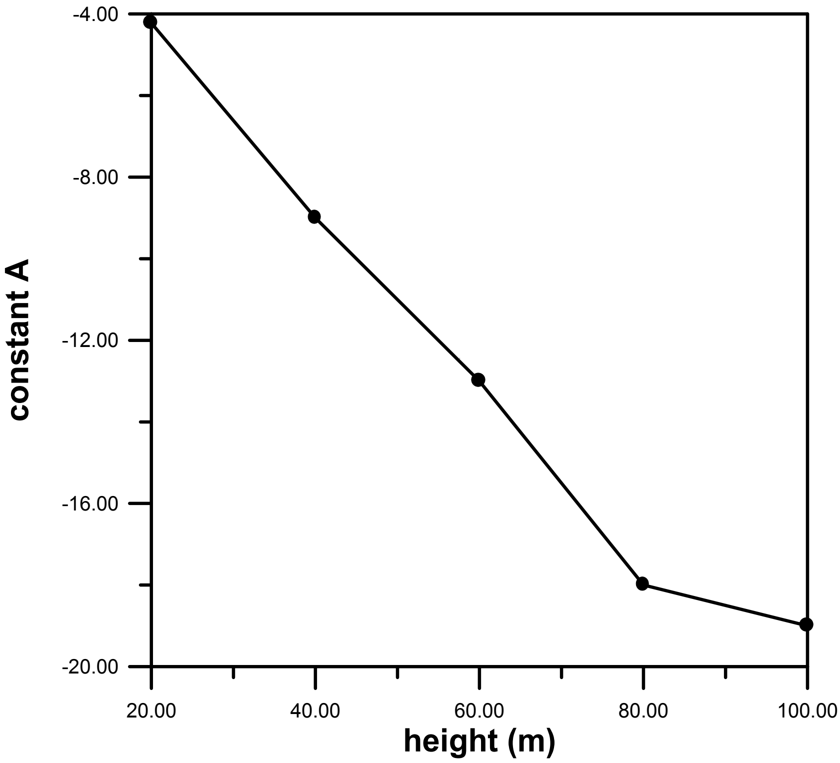

Figure 4-2 The Relation Between the Constant A and the Height.

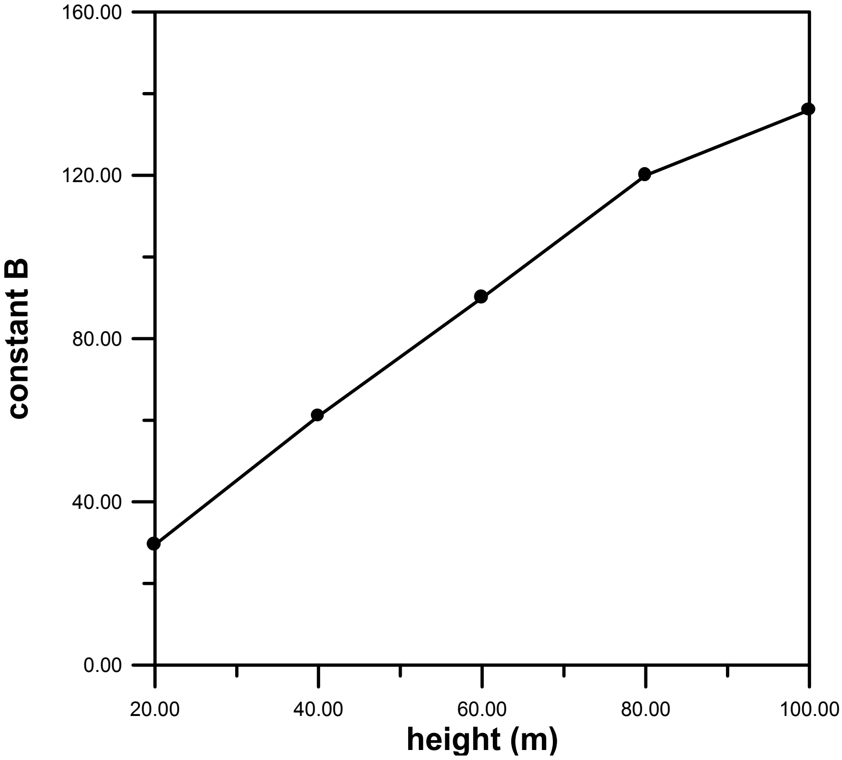

Figure 4-3 The Relation Between the Constant B and the Height.

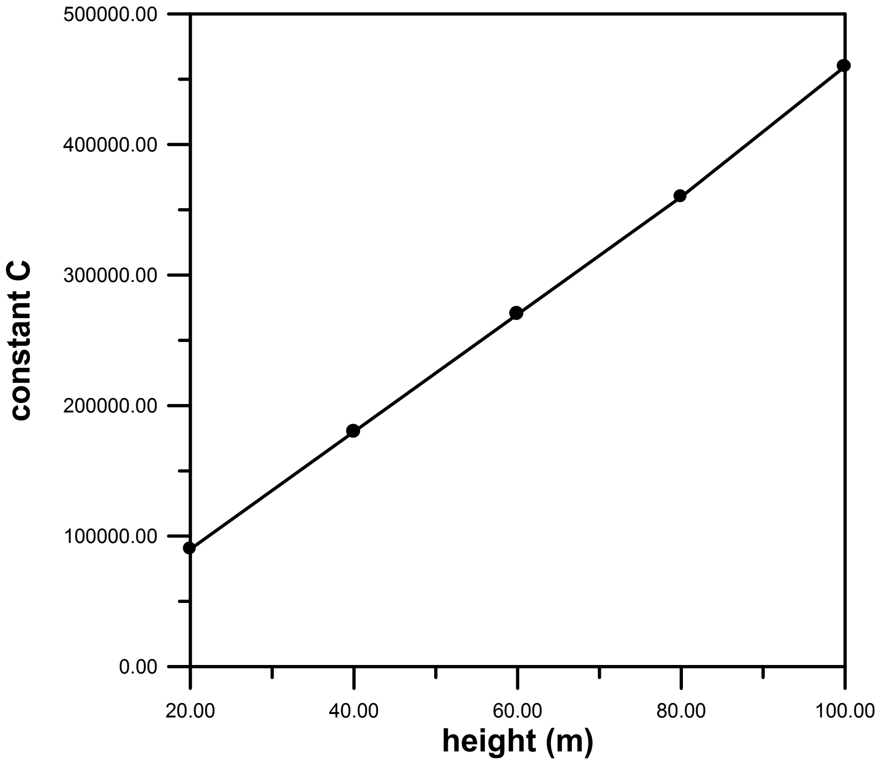

Figure 4-4 The Relation Between the Constant C and the Height.

In order to make equation (4-1) more useful and accurate, equations for the constants A, B, and C would be obtained from a software program according to the data in Table 4-2, so, now the displacement of the particle could be calculated for each value of height and diameter.
The equations are (4-2), (4-3), (4-4).

$$A = 9.75 - 3.37H^{0.47} \qquad \ldots (4\text{-}2)$$

$$B = -33.7 + 9.4H^{0.63} \qquad \ldots (4\text{-}3)$$

$$C = 16175 + 2794H^{1.1} \qquad \ldots (4\text{-}4)$$

After substituting equations (4-2), (4-3), and (4-4) in equation (4-1), the following equation would be obtained:

$$L = 9.75 - 3.37H^{0.47} + \frac{\left(-33.7 + 9.4H^{0.63}\right)}{D^{0.24}} + \frac{\left(16175 + 2794H^{1.1}\right)}{D^{2}} \quad \ldots (4\text{-}5)$$

Equation (4-5) represents the displacement of the particle, when the first case of constant gas velocity is taken place.

4.3.2 Constant Height of the Chamber

The height of the chamber was fixed on assumed value of 20 m and different values of the gas velocity have been taken. For each taken assumed value of gas velocity and fixed value of height, different values of diameter have been used.

As a result, numbers of values of the displacement have been obtained facing to the same numbers of values of the diameter have been substituted, these procedures explained above have been calculated by a program Appendix A-1 which all needed equations that entered in calculations of the displacement have been inserted in it. This idea has been explained clearly in Table 4-3.

Table 4-3 The Relation Between the Diameter and the Length at Constant Height of Chamber and Different Gas Velocity.

Height of Chamber = 20 (m)					
Diameter (μm)	Length (displacement) (m)				
	Vg=0.5	Vg=0.8	Vg=1.2	Vg=1.8	Vg=2.6
1	9×10^4	1.46×10^5	2.2×10^5	3.3×10^5	4.7×10^5
50	43	69	103	155	223
100	15.4	24.5	37	55	80
150	8.7	14	21	31.4	45
200	6.3	10	15	22.7	33
250	5	8	11.7	17.6	25
300	4	6.4	9.6	14.3	20.7
350	3.3	5.4	8	12	17.4
400	3	4.6	7	10.4	15
450	3	5	7	11	16
500	3	4	7	10	14
550	3	4	6	9	13
600	2	4	6	8	12
650	2	4	5	8	11
700	2	3	5	7	11
750	2	3	5	7	10
800	2	3	4	7	10
850	2	3	4	6	9
900	2	3	4	6	9

We noticed from Table 4-3 that the length decreases with increasing the diameter as in first case of constant gas velocity, and that reasonable, because when the particle gets larger, the displacement of it will decrease and that an opposite relationship between the particle diameter and the length. This relationship becomes clearly understandable when it is illustrated in Figure 4-5.

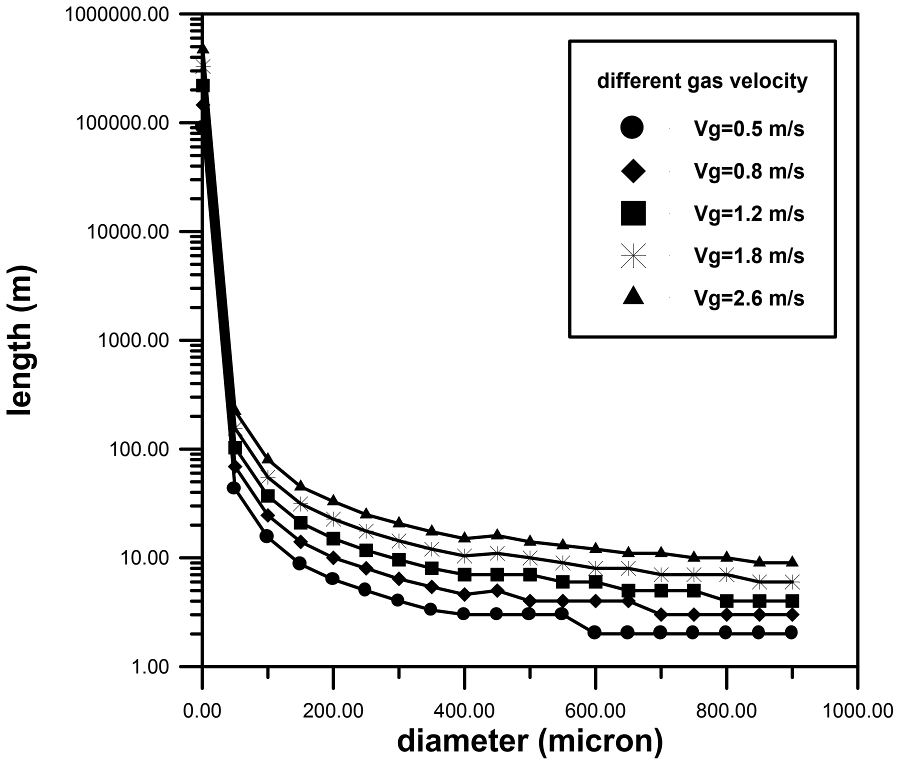

Figure 4-5 The Relation Between the Length and the Diameter at Different Values of Gas Velocity.

As in case of different heights, the curves in Figure 4-5 have been represented by equation (4-1) made by means of a software program in order to get an equation for the displacement as a function of the diameter.

The constants A, B, and C for the five curves when the displacement and the diameter in Table 4-3 have been substituted in equation (4-1), would be:

Table 4-4 The Different Values of Constants A, B, and C to each Value of Gas Velocity.

Vg (m/s)	A	B	C
0.5	-4.22	29.5	89974.7
0.8	-6.4	45	145961
1.2	-9.3	66	219943
1.8	-14	100	329914
2.6	-22	152	469870

The constants B and C are increasing with increasing the gas velocity. So it is obvious that the relation is directly proportional and a straight line relation is taken place, while constant A takes an opposite relation with the gas velocity, as it is illustrated in Figures 4-6, 4-7, 4-8.

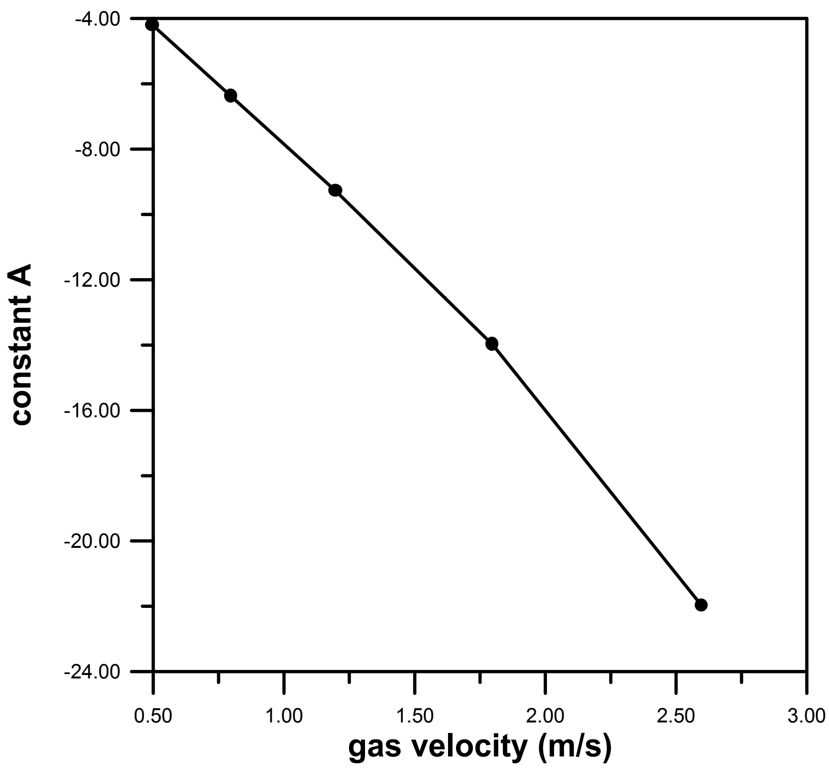

Figure 4-6 The Relation Between the Constant A and the Gas Velocity.

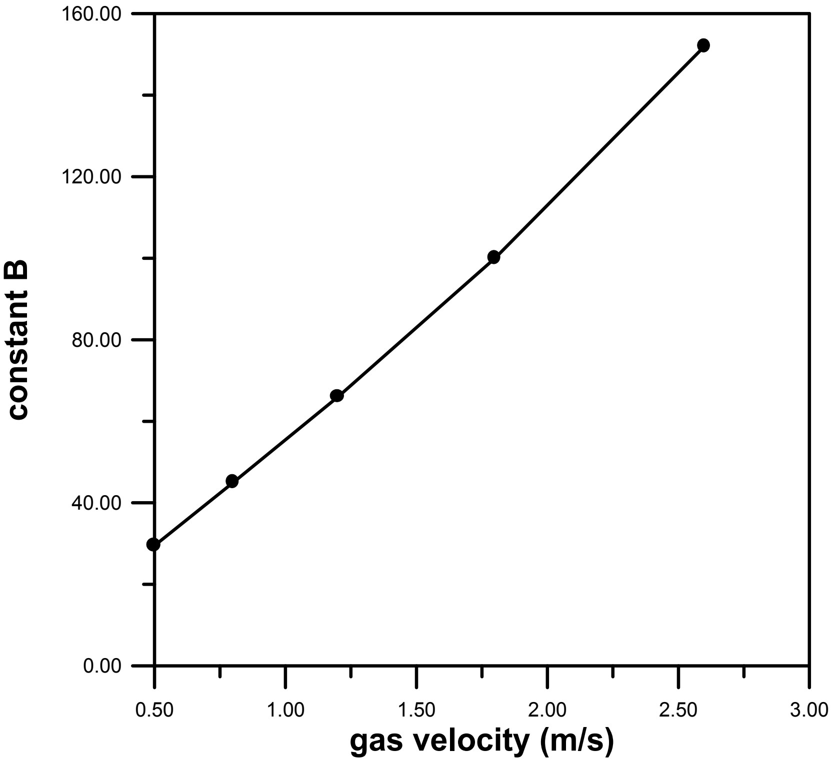

Figure 4-7 The Relation Between the Constant B and the Gas Velocity.

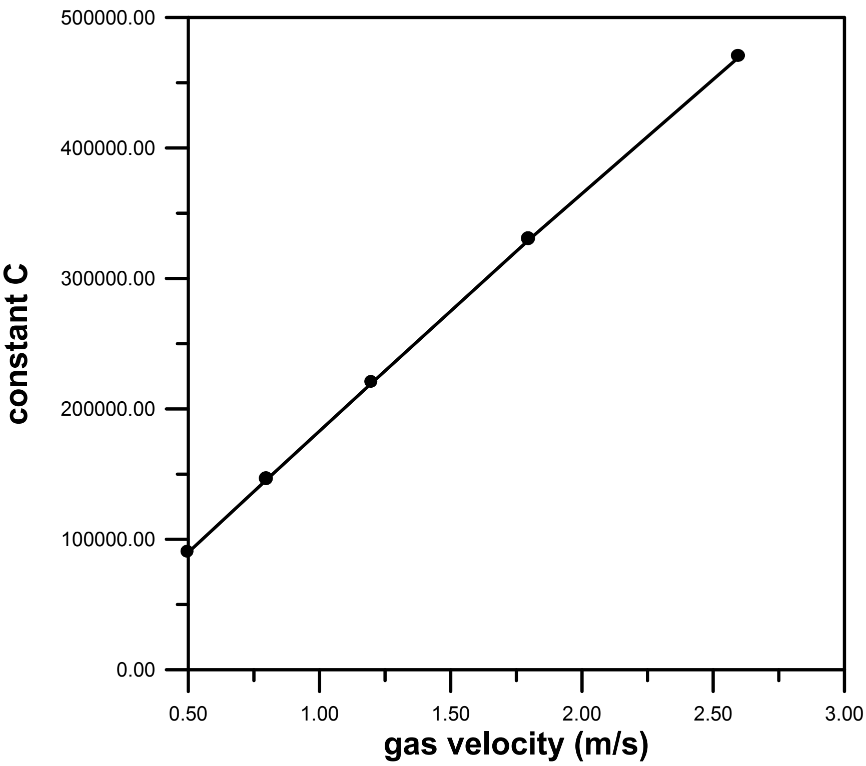

Figure 4-8 The Relation Between the Constant C and the Gas Velocity.

In order to make equation (4-1) more useful and accurate, equations for the constants A, B, and C would be obtained from software program according to the data in Table 4-4, so, now the displacement of the particle could be calculated for each value of the gas velocity and diameter.
The equations are (4-6), (4-7), (4-8).

$$A = -2.2 - 5.4Vg^{1.35} \quad \ldots (4\text{-}6)$$

$$B = 11.5 + 43.3Vg^{1.23} \quad \ldots (4\text{-}7)$$

$$C = -13117.7 + 196857Vg^{0.94} \quad \ldots (4\text{-}8)$$

After substituting equations (4-6), (4-7), and (4-8) in equation (4-1), the following equation would be obtained:

$$L = -2.2 - 5.4Vg^{1.35} + \frac{\left(11.5 + 43.3Vg^{1.23}\right)}{D^{0.24}} + \frac{\left(-13117.7 + 196857Vg^{0.94}\right)}{D^{2}} \quad \ldots (4\text{-}9)$$

Equation (4-9) represents the displacement of the particle, when the second case of constant height of chamber is taken place.

In order to get an equation that represents the displacement of the particle as a function of the diameter of the particle, the height of the chamber, and the velocity of the gas, equations (4-5) and (4-9) have been added for one general equation, and the equation is:

$$L = \frac{\left[7.55 - 3.37H^{0.47} - 5.4Vg^{1.35} + \frac{\left(-22.2 + 9.4H^{0.63} + 43.3Vg^{1.23} \right)}{D^{0.24}} + \frac{\left(3057 + 2794H^{1.1} + 196857Vg^{0.94} \right)}{D^{2}} \right]}{C}$$

… (4-10)

In equation (4-10) the value of C came to make the calculated displacement more accuracy and exactness, and it has been evaluated by a software program that offered best fitting for the values of displacement that calculated from equations (3-29), (3-32), and (3-33), and also offered the minimum error as possible as it could.

Each case of constant gas velocity and constant height of chamber has certain equation for C that has been extracted from a software program, which means that there is an equation defines the value of C when the height of chamber has different values, and also an equation that defines C when the gas velocity has different values.
The equation of C was come from different values of C at different values of the height and the gas velocity, as explained in Tables 4-5, 4-6.

Table 4-5 Values of C at Different Heights.

Height of the Chamber (m)	Value of C
20	**2.012**
40	**1.485**
60	**1.327**
80	**1.256**
100	**1.193**

Table 4-6 Values of C at Different Gas Velocities.

Velocity of the gas (m/s)	Value of C
0.5	**2.012**
0.8	**1.631**
1.2	**1.42**
1.8	**1.275**
2.6	**1.196**

From Tables 4-5, 4-6, equations (4-11), (4-12) have been extracted by a software program

The equation for C at constant gas velocity would be

$$C = 1.037 + \frac{27.07}{H^{1.11}} \quad \ldots (4\text{-}11)$$

The equation for C at constant chamber height would be

$$C = 1.004 + \frac{0.5}{Vg^{1.015}} \quad \ldots (4\text{-}12)$$

The values of C after using equations (4-11), (4-12) would be:

Table 4-7 Values of C at Different Heights.

Height of the Chamber (m)	Value of C
20	2.0105
40	1.488
60	1.324
80	1.245
100	1.2

Table 4-8 Values of C at Different Gas Velocities.

Velocity of the Gas (m/s)	Value of C
0.5	2.014
0.8	1.631
1.2	1.419
1.8	1.279
2.6	1.193

Tables 4-7 and 4-8 have been plotted, for more understanding of the relation and in order to get any value of C that does not exist in the tables above from Figures 4-9 and 4-10.

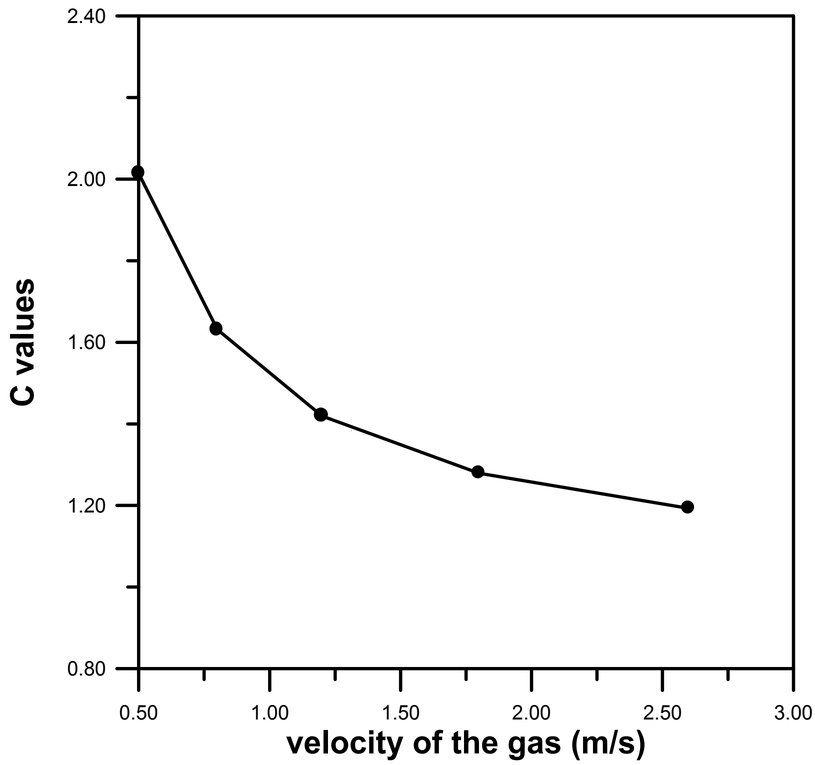

Figure 4-9 The Relation Between C Values and Velocity of the Gas.

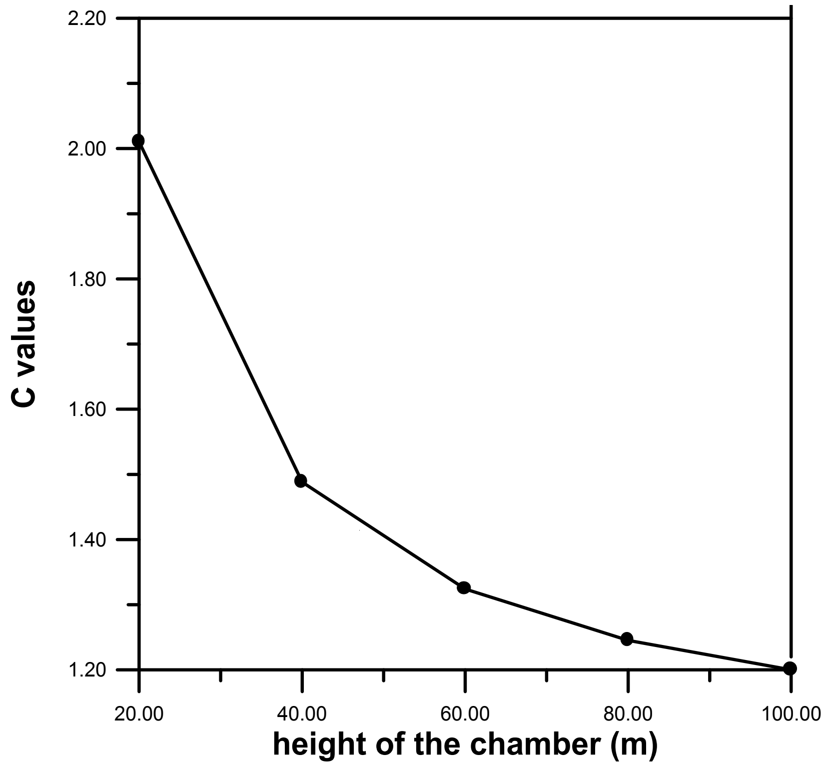

Figure 4-10 The Relation Between C Values and Height of the Chamber.

The value that calculated from either equation (4-11) or equation (4-12) each according to its case of constant gas velocity or constant chamber height, would be substituted in equation (4-10), in order to get wanted displacement at a given diameter of the particle, height of the chamber, velocity of the gas when either the height is varying or the velocity is varying.

Equation (4-10) gives approximate values of displacement with minimum error when the diameter taken up to 900 µm, more than 900 µm the values of displacement would act irregular and abnormal, and it would increase with increasing the diameter and that does not acceptable because when the particle gets larger and increasing with its diameter the displacement of it would decrease as it is explained in Tables 4-1, and 4-3.

Table 4-9 A Comparison Between Length Results Obtained from Equations (4-10), (4-11) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (μm)	Height of the Chamber = 20 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equations (4-10) and (4-11) (m)	Absolute percent error
1	90000	90083.65	0.09
50	43	43.19	0.44
100	15.4	14.43	6.26
150	8.7	8.54	1.82
200	6.3	6.2	1.45
250	5	4.97	0.51
300	4	4.2	5.1
350	3.3	3.67	11.2
400	3	3.27	9.13
450	3	2.96	1.2
500	3	2.71	9.59
550	3	2.5	16.6
600	2	2.32	16.1
650	2	2.16	8.3
700	2	2.03	1.47
750	2	1.9	4.66
800	2	1.79	10.18
850	2	1.69	15.19
900	2	1.6	19.78
Average Error			7.3

Table 4-10 A Comparison Between Length Results Obtained from Equations (4-10), (4-11) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (µm)	Height of the Chamber = 40 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equations (4-10) and (4-11) (m)	Absolute percent error
1	180000	179679.4	0.18
50	86	86.9	1.05
100	31	29.29	5.5
150	17	17.4	2.42
200	12.6	12.67	0.6
250	9.8	10.15	3.59
300	8	8.56	7.11
350	6.7	7.46	11.4
400	6	6.64	10.7
450	6	5.99	0.07
500	6	5.47	8.84
550	5	5.03	0.59
600	5	4.65	6.9
650	4	4.32	8.12
700	4	4.03	0.88
750	4	3.77	5.59
800	4	3.54	11.4
850	3	3.33	11
900	3	3.13	4.55
Average Error			5.3

Table 4-11 A Comparison Between Length Results Obtained from Equations (4-10), (4-11) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (µm)	Height of the Chamber = 60 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equations (4-10) and (4-11) (m)	Absolute percent error
1	270000	270565	0.21
50	129	130.34	1.04
100	46	43.75	4.89
150	26	25.93	0.26
200	19	18.85	0.77
250	15	15.09	0.61
300	12	12.73	6.13
350	10	11.09	10.99
400	8.6	9.88	14.88
450	9	8.92	0.85
500	8	8.14	1.83
550	8	7.49	6.29
600	7	6.94	0.84
650	7	6.45	7.75
700	6	6.03	0.52
750	6	5.65	5.83
800	6	5.3	11.55
850	5	4.99	0.09
900	5	4.71	5.81
Average Error			4.2

Table 4-12 A Comparison Between Length Results Obtained from Equations (4-10), (4-11) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (μm)	Height of the Chamber = 80 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equations (4-10) and (4-11) (m)	Absolute percent error
1	360000	363234.6	0.9
50	172	173.85	1.08
100	61	57.94	5.01
150	35	34.19	2.3
200	25	24.8	0.8
250	19.6	19.83	1.18
300	16	16.73	4.57
350	13	14.58	12.2
400	11.5	12.99	12.97
450	12	11.74	2.12
500	11	10.73	2.42
550	10	9.88	1.11
600	9	9.16	1.87
650	9	8.54	5.08
700	8	7.99	0.12
750	8	7.49	6.27
800	7	7.05	0.79
850	7	6.65	4.96
900	7	6.28	10.23
Average Error			4

Table 4-13 A Comparison Between Length Results Obtained from Equations (4-10), (4-11) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (μm)	Height of the Chamber = 100 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equations (4-10) and (4-11) (m)	Absolute percent error
1	460000	457189.9	0.61
50	215	217.37	1.11
100	77	71.9	6.62
150	43.6	42.22	3.15
200	31.5	30.54	3.03
250	24.5	24.39	0.44
300	20	20.57	2.86
350	16.7	17.93	7.4
400	14.4	15.98	11
450	15	14.46	3.59
500	14	13.22	5.51
550	13	12.2	6.14
600	12	11.32	5.6
650	11	10.56	3.93
700	10	9.89	1.01
750	10	9.3	6.96
800	9	8.76	2.58
850	9	8.28	7.98
900	8	7.83	2.04
Average Error			4.2

Table 4-14 A Comparison Between Length Results Obtained from Equations (4-10), (4-12), and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (µm)	Velocity of the Gas = 0.5 (m/s)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equations (4-10) and (4-12) (m)	Absolute percent error
1	90000	89927.1	0.08
50	43	43.12	0.27
100	15.4	14.4	6.43
150	8.7	8.53	1.99
200	6.3	6.2	1.62
250	5	4.97	0.69
300	4	4.2	4.92
350	3.3	3.66	11.03
400	3	3.27	8.94
450	3	2.96	1.38
500	3	2.71	9.75
550	3	2.5	16.74
600	2	2.32	15.93
650	2	2.16	8.15
700	2	2.03	1.29
750	2	1.9	4.82
800	2	1.79	10.33
850	2	1.69	15.34
900	2	1.6	19.92
Average Error			7.3

Table 4-15 A Comparison Between Length Results Obtained from Equations (4-10), (4-12), and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (μm)	Velocity of the Gas = 0.8 (m/s)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equations (4-10) and (4-12) (m)	Absolute percent error
1	146000	145999.8	0.0001
50	69	69.53	0.77
100	24.5	23.07	5.83
150	14	13.59	2.9
200	10	9.86	1.4
250	8	7.89	1.32
300	6.4	6.67	4.26
350	5.4	5.83	7.97
400	4.6	5.21	13.18
450	5	4.72	5.61
500	4	4.33	8.14
550	4	4	0.07
600	4	3.72	7.07
650	4	3.47	13.14
700	3	3.26	8.69
750	3	3.07	2.34
800	3	2.9	3.37
850	3	2.74	8.56
900	3	2.6	13.3
Average Error			5.6

Table 4-16 A Comparison Between Length Results Obtained from Equations (4-10), (4-12), and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (µm)	Velocity of the Gas = 1.2 (m/s)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equations (4-10) and (4-12) (m)	Absolute percent error
1	220000	220009.9	0.005
50	103	104.6	1.56
100	37	34.65	6.35
150	21	20.4	2.87
200	15	14.79	1.39
250	11.7	11.84	1.2
300	9.6	10	4.3
350	8	8.75	9.4
400	7	7.82	11.7
450	7	7.09	1.3
500	7	6.5	7.1
550	6	6.01	0.22
600	6	5.6	6.7
650	5	5.23	4.6
700	5	4.92	1.7
750	5	4.63	7.37
800	4	4.38	9.4
850	4	4.14	3.6
900	4	3.93	1.68
Average Error			4.3

Table 4-17 A Comparison Between Length Results Obtained from Equations (4-10), (4-12), and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (μm)	**Velocity of the Gas = 1.8 (m/s)**		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	**Length calculated from Equations (4-10) and (4-12) (m)**	**Absolute percent error**
1	**330000**	**328873.7**	**0.34**
50	**155**	**156.7**	**1.12**
100	**55**	**52.05**	**5.36**
150	**31.4**	**30.69**	**2.26**
200	**22.7**	**22.27**	**1.88**
250	**17.6**	**17.8**	**1.36**
300	**14.3**	**15.08**	**5.48**
350	**12**	**13.18**	**9.85**
400	**10.4**	**11.77**	**13.2**
450	**11**	**10.67**	**2.97**
500	**10**	**9.78**	**2.17**
550	**9**	**9.04**	**0.46**
600	**8**	**8.4**	**5.11**
650	**8**	**7.86**	**1.74**
700	**7**	**7.37**	**5.39**
750	**7**	**6.94**	**0.76**
800	**7**	**6.55**	**6.3**
850	**6**	**6.2**	**3.46**
900	**6**	**5.88**	**1.9**
Average Error			**3.7**

Table 4-18 A Comparison Between Length Results Obtained from Equations (4-10), (4-12), and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (μm)	Velocity of the Gas = 2.6 (m/s)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equations (4-10) and (4-12) (m)	Absolute percent error
1	470000	471013.6	0.216
50	223	225.68	1.206
100	80	75.37	5.78
150	45	44.58	0.933
200	33	32.39	1.82
250	25	25.95	3.8
300	20.7	21.93	5.95
350	17.4	19.15	10.05
400	15	17.08	13.88
450	16	15.46	3.34
500	14	14.15	1.097
550	13	13.05	0.45
600	12	12.12	1.03
650	11	11.3	2.83
700	11	10.59	3.67
750	10	9.95	0.43
800	10	9.38	6.181
850	9	8.86	1.56
900	9	8.38	6.87
Average Error			3.7

The average error of equation (4-10) at constant gas velocity and when equation (4-11) was used is 5%, where as the average error of the same equation at constant chamber height and when equation (4-12) was used, is 4.9%.

In order to make equation (4-10) a general equation for all cases without using equation (4-11), (4-12) which represent the value of C at constant velocity of the gas and constant height of the chamber. In this case, an average of the C values that exist in Tables 4-7, 4-8 has been taken and substituted in equation (4-10).
From equation (4-10) with average value of C which equals to 1.48, the displacement of the particle can be obtained directly from only the values of gas velocity, chamber height, and diameter of the particle without returning to the two cases of different height and different velocity which is represented by equations (4-11) and (4-12).

The error estimated in this case would be high compared with the error obtained in the case when either the height of the chamber is different or the velocity of the gas is different. As it is shown in the Tables below

$$L = \frac{\left[7.55 - 3.37H^{0.47} - 5.4Vg^{1.35} + \frac{\left(-22.2 + 9.4H^{0.63} + 43.3Vg^{1.23}\right)}{D^{0.24}} + \frac{\left(3057 + 2794H^{1.1} + 196857Vg^{0.94}\right)}{D^{2}} \right]}{1.48}$$

… (4-13)

Table 4-19 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (µm)	Height of the Chamber = 20 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equation (4-13) (m)	Absolute percent error
1	90000	122373.8	35.9
50	43	58.67	36.4
100	15.4	19.6	27
150	8.7	11.6	33
200	6.3	8.4	33.8
250	5	6.7	35
300	4	5.7	42.7
350	3.3	4.9	51
400	3	4.4	48
450	3	4	34
500	3	3.6	22.8
550	3	3.4	13.3
600	2	3.1	57.7
650	2	3	47
700	2	2.7	37.8
750	2	2.6	29.5
800	2	2.4	22
850	2	2.3	15
900	2	2.18	9
Average Error			33.3

Table 4-20 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (µm)	Height of the Chamber = 40 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equation (4-13) (m)	Absolute percent error
1	180000	180650.6	0.36
50	86	87.4	1.6
100	31	29.4	4.9
150	17	17.5	2.9
200	12.6	12.7	1.14
250	9.8	10.2	4.15
300	8	8.6	7.7
350	6.7	7.5	12
400	6	6.7	11.3
450	6	6	0.47
500	6	5.5	8.3
550	5	5	1.13
600	5	4.7	6.4
650	4	4.35	8.7
700	4	4	1.4
750	4	3.8	5
800	4	3.5	10.9
850	3	3.35	11.6
900	3	3.15	5
Average Error			5.5

Table 4-21 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (μm)	Height of the Chamber = 60 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equation (4-13) (m)	Absolute percent error
1	270000	242045.9	10.35
50	129	116.6	9.6
100	46	39	14.9
150	26	23.2	10.7
200	19	16.8	11.2
250	15	13.5	10
300	12	11.4	5
350	10	9.9	0.7
400	8.6	8.8	2.7
450	9	7.9	11.3
500	8	7.3	8.9
550	8	6.7	16.17
600	7	6.2	11.3
650	7	5.8	17.47
700	6	5.4	10
750	6	5	15.7
800	6	4.7	20.8
850	5	4.5	10.6
900	5	4.2	15.7
Average Error			11.2

Table 4-22 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (µm)	Height of the Chamber = 80 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equation (4-13) (m)	Absolute percent error
1	360000	305558.8	15
50	172	146.25	14.1
100	61	48.7	20
150	35	28.7	17.8
200	25	20.8	16.5
250	19.6	16.7	14.9
300	16	14	12
350	13	12.3	5.6
400	11.5	10.9	4.9
450	12	9.8	17.6
500	11	9	17.9
550	10	8.3	16.8
600	9	7.7	14.3
650	9	7.2	20
700	8	6.7	15.9
750	8	6.3	21
800	7	5.9	15
850	7	5.6	20
900	7	5.3	24.5
Average Error			16

Table 4-23 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Velocity of the Gas = 0.5 (m/s)			
Diameter (μm)	Height of the Chamber = 100 (m)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equation (4-13) (m)	Absolute percent error
1	460000	370694.5	19.4
50	215	176.25	18
100	77	58.3	24.3
150	43.6	34.2	21.4
200	31.5	24.7	21.4
250	24.5	19.8	19.27
300	20	16.7	16.6
350	16.7	14.5	12.9
400	14.4	13	10
450	15	11.7	21.8
500	14	10.7	23.4
550	13	9.9	23.9
600	12	9.2	23.4
650	11	8.5	22.1
700	10	8	19.7
750	10	7.5	24.5
800	9	7.1	21
850	9	6.7	25.4
900	8	6.3	20.5
Average Error			20.5

Table 4-24 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (µm)	**Velocity of the Gas = 0.5 (m/s)**		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	**Length calculated from Equation (4-13) (m)**	**Absolute percent error**
1	90000	122373.8	35.9
50	43	58.67	36.4
100	15.4	19.6	27
150	8.7	11.6	33
200	6.3	8.4	33.8
250	5	6.7	35
300	4	5.7	42.7
350	3.3	4.9	51
400	3	4.4	48
450	3	4	34
500	3	3.6	22.8
550	3	3.4	13.3
600	2	3.1	57.7
650	2	3	47
700	2	2.7	37.8
750	2	2.6	29.5
800	2	2.4	22
850	2	2.3	15
900	2	2.18	9
Average Error			33.3

Table 4-25 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (µm)	Velocity of the Gas = 0.8 (m/s)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equation (4-13) (m)	Absolute percent error
1	146000	160895.7	10.2
50	69	76.6	11
100	24.5	25.4	3.78
150	14	14.9	7
200	10	10.87	8.6
250	8	8.7	8.7
300	6.4	7.3	14.9
350	5.4	6.4	18.9
400	4.6	5.7	24.7
450	5	5.2	4
500	4	4.77	19
550	4	4.4	10
600	4	4.1	2.4
650	4	3.8	4.27
700	3	3.6	19.7
750	3	3.4	12.8
800	3	3.2	6.5
850	3	3	0.77
900	3	2.87	4.4
Average Error			10

Table 4-26 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (µm)	Velocity of the Gas = 1.2 (m/s)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equation (4-13) (m)	Absolute percent error
1	220000	210942	4.12
50	103	100	2.6
100	37	33	10.2
150	21	19.5	6.8
200	15	14.18	5.4
250	11.7	11.35	2.9
300	9.6	9.6	0.0027
350	8	8.4	4.9
400	7	7.5	7
450	7	6.8	2.8
500	7	6.2	10.9
550	6	5.7	3.9
600	6	5.37	10.6
650	5	5	0.36
700	5	4.7	5.7
750	5	4.4	11.2
800	4	4.2	4.8
850	4	4	0.66
900	4	3.7	5.7
Average Error			5.3

Table 4-27 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (μm)	**Velocity of the Gas = 1.8 (m/s)**		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	**Length calculated from Equation (4-13) (m)**	**Absolute percent error**
1	330000	284209	13.8
50	155	135	12.6
100	55	44.9	18.2
150	31.4	26.5	15.5
200	22.7	19	15.2
250	17.6	15.4	12.4
300	14.3	13	8.8
350	12	11.4	5
400	10.4	10	2.2
450	11	9.2	16
500	10	8.45	15.4
550	9	7.8	13.2
600	8	7.3	9.16
650	8	6.8	15
700	7	6.4	9
750	7	6	14.2
800	7	5.6	19
850	6	5.3	10.6
900	6	5	15
Average Error			12.6

Table 4-28 A Comparison Between Length Results Obtained from Equation (4-13) and Equations (3-29), (3-32), (3-33).

Height of the Chamber = 20 (m)			
Diameter (µm)	Velocity of the Gas = 2.6 (m/s)		
	Length calculated from Equations (3-29), (3-32) and (3-33) (m)	Length calculated from Equation (4-13) (m)	Absolute percent error
1	470000	379675	19.2
50	223	181.9	18.4
100	80	60.7	24
150	45	35.9	20
200	33	26	20.8
250	25	20.9	16.3
300	20.7	17.7	14.6
350	17.4	15.4	11.3
400	15	13.7	8.2
450	16	12.4	22
500	14	11.4	18.5
550	13	10.53	19
600	12	9.7	18.5
650	11	9.1	17
700	11	8.5	22.4
750	10	8	19.7
800	10	7.5	24.3
850	9	7.1	20.8
900	9	6.7	25
Average Error			19

The average error of equation (4-13) for the two cases of constant velocity of the gas and constatnt height of the chamber is 16.7%.

4.4 Obtaining the Displacement in Terms of Statistical Distribution

In section (4-3) equation for estimating the displacement of one particle has been obtained, that means equation (4-10) was suitable only when the diameter of single particle has been substituted to get the displacement of this single particle at certain diameter after knowing the height of the chamber and the velocity of the gas. So equation (4-10) is helped in estimating the displacement for certain particle at certain diameter.

To make equation (4-10) more specific and suitable for more than one certain diameter, there are statistical distribution equations, which equation (4-10) could be in terms of them, so the displacement of a mixture of particles and their distribution would now be obtained.

After substituting equation (3-39) in (4-10), equation (4-14) was obtained.

$$L = \frac{\left[7.55 - 3.37H^{0.47} - 5.4Vg^{1.35} + \frac{\left(-22.2 + 9.4H^{0.63} + 43.3Vg^{1.23}\right)}{\left(x_{80/3} \left[\frac{H_3(x)}{0.8} \right]^{1/K} \right)^{0.24}} + \frac{\left(3057 + 2794H^{1.1} + 196857Vg^{0.94}\right)}{\left(x_{80/3} \left[\frac{H_3(x)}{0.8} \right]^{1/K} \right)^{2}} \right]}{C}$$

… (4-14)

The displacement now in equation (4-14) became as a function of a kind of distribution and under the influence of the parameters that included in the distribution equation such as the *k* value and the $x_{80/3}$ value, so a study has been done using software program Appendix A-2 for illustrating the relation between different values of *k* and the displacement, at constant $x_{80/3}$ once and the relation between different values of $x_{80/3}$ and the displacement, at constant *k* another.

The value of C in equation (4-14) has been calculated from the two equations (4-11) and (4-12) and it was found that the two calculated values are closed together, as a result the values of displacement estimated after substituting these two values of C were similar, so equation (4-11) was used, and that will be explained in Tables 4-29, 4-30.

In Table 4-29, different assumed values of *k* have been taken and substituted in equation (4-14) obtaining as a result, values of displacement. Values that exist in the first column represent the percentage that a certain diameter exists by, so the Table shows values of the displacement that a certain percentage of any diameter reaches to.

Table 4-29 The Relation Between the *k* Values and the Displacement at Constant $x_{80/3}$ when V_g=o.5 m/s and H=20 m.

$x_{80/3} = 10$					
$H_3(x)$	Length (displacement) (m)				
	$k=2 \times 10^3$	$k=8 \times 10^3$	$k=14 \times 10^3$	$k=20 \times 10^3$	$k=26 \times 10^3$
0.1	230	3700	11300	23000	39000
0.2	57.6	920	2800	5700	9700
0.3	25.6	400	1250	2500	4300

0.4	**14**	**230**	**700**	**1400**	**2400**
0.5	**9**	**147**	**450**	**900**	**1560**
0.6	**6.4**	**100**	**300**	**640**	**1100**
0.7	**4.7**	**75**	**230**	**470**	**790**
0.8	**3.6**	**57**	**176**	**360**	**610**
0.9	**2.8**	**45**	**140**	**280**	**480**
1	**2.3**	**37**	**113**	**230**	**390**

It is obvious from Table 4-29, that the displacement values increased with increasing the *k* values and decreased with increasing the percentage of a mixture of a certain diameter and that is reasonable because this percentage of any diameter represents a certain amount that includes particles with given diameter and that amount has certain weight, so when this weight increased, the displacement decreased. This relation is illustrated in Figure 4-11.

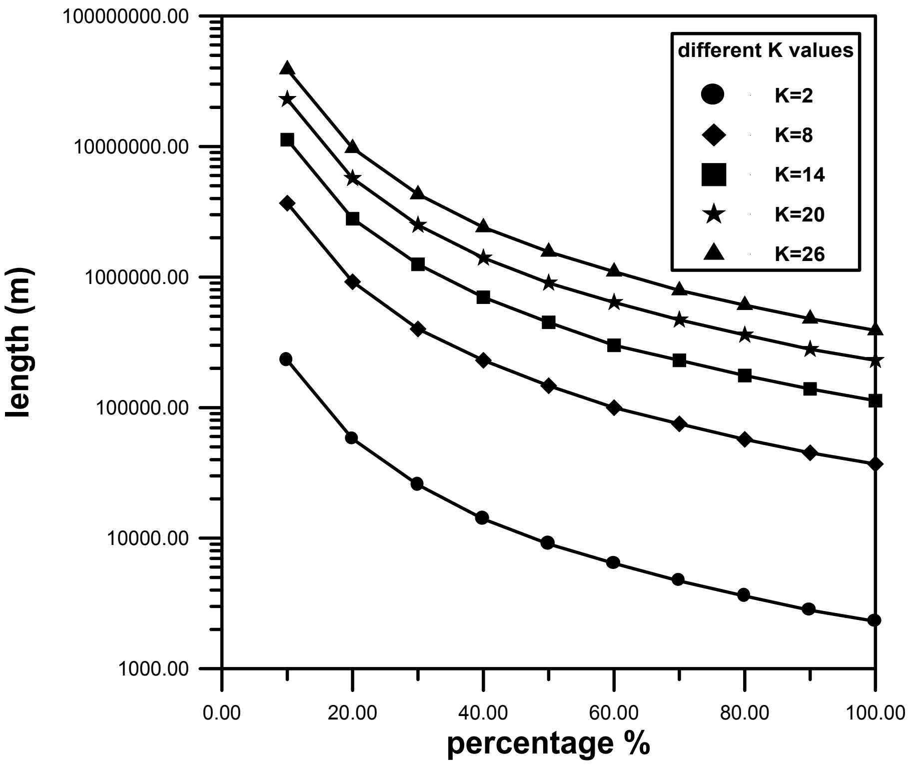

Figure 4-11 The Relation Between the Percentage and the Displacement at Different *k* Values.

In Table 4-30, different assumed values of $x_{80/3}$ have been taken and substituted in equation (4-14) obtaining as a result, values of displacement.

Table 4-30 The Relation Between the $x_{80/3}$ Values and the Displacement at Constant *k*.

$k = 2$					
$H_3(x)$	**Length (displacement) (m)**				
	$x_{80/3}$=10 ×10^3	**$x_{80/3}$=20 ×10^3**	**$x_{80/3}$=30 ×10^3**	**$x_{80/3}$=40 ×10^3**	**$x_{80/3}$=50 ×10^3**
0.1	**230**	**57.6**	**25.6**	**14**	**9.2**
0.2	**57.6**	**14**	**6.4**	**3.6**	**2.3**
0.3	**25.6**	**6.4**	**2.8**	**1.6**	**1**
0.4	**14**	**3.6**	**1.6**	**0.913**	**0.588**
0.5	**9**	**2.3**	**1**	**0.588**	**0.3797**
0.6	**6.4**	**1.6**	**0.723**	**0.411**	**0.266**
0.7	**4.7**	**1.2**	**0.534**	**0.3045**	**0.1978**
0.8	**3.6**	**0.913**	**0.411**	**0.235**	**0.153**
0.9	**2.8**	**0.7236**	**0.3268**	**0.187**	**0.1227**
1	**2.3**	**0.588**	**0.2664**	**0.153**	**0.1007**

It is obvious from Table 4-30 that the displacement values decreased with increasing the $x_{80/3}$ values and decreased with increasing the percentage which represents a quantity of particles with certain diameter in percent, so when the weight represented by this quantity increased, the displacement of the particles decreased. This relation is illustrated in Figure 4-12.

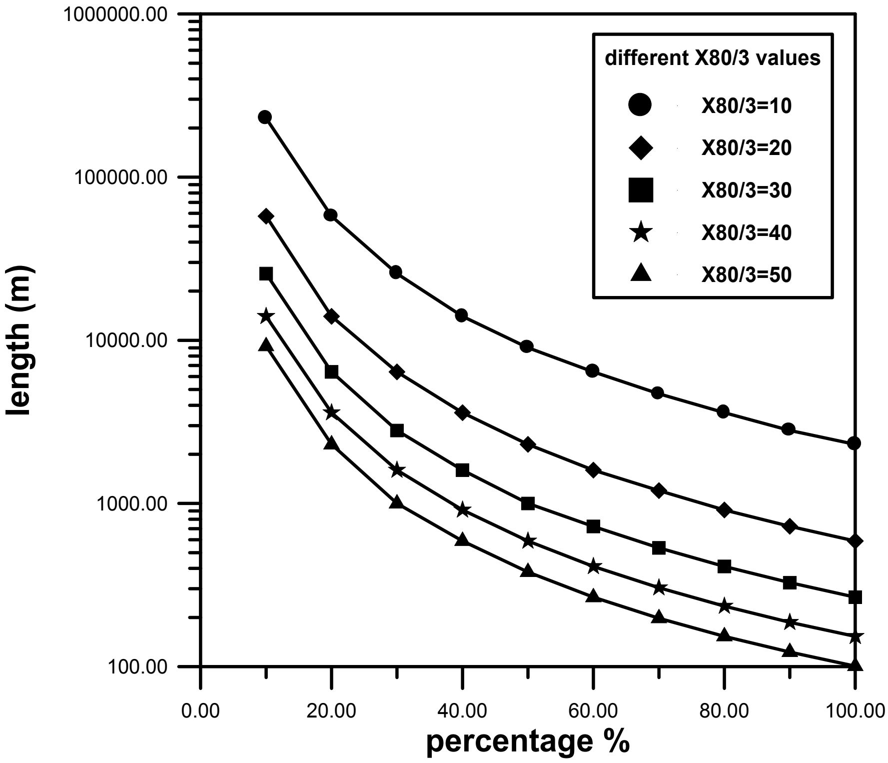

Figure 4-12 The Relation Between the Percentage and the Displacement at Different $x_{80/3}$ Values.

Chapter Five

Conclusions and Recommendations for Future Work

5.1 Conclusions

1. An equation for the displacement of the particle as a function of height of the chamber, velocity of the gas and diameter of the particle has been obtained. This equation also enables us to determine the length of the chamber by knowing the height of the chamber, the velocity of the gas, and the diameter of the particle.
2. Estimation of the length of the chamber was made by assuming the velocity of the gas, the height of the chamber, while the settling velocity has been determined by assuming the diameter using certain equation.
3. The estimated value of the length represents the displacement that a particle of a certain diameter needs to settle. So the particle with diameter larger than this certain diameter will settle out of the chamber, whereas the particles with diameter smaller than this certain diameter will settle inside the chamber. And that helps in designing a chamber with certain length for containing a desired diameter of the particle.
4. In order to estimate the displacement of a certain mixture of grains, an equation for this displacement in terms of statistical distributions has been obtained.

5.2 Recommendations for Future Work

1. Repeating the calculations by using other fluid, except the air and other particles, except the dust particles, to obtain an equation for displacement of the particle or length of the chamber in other circumstances.
2. Using other statistical distributions equations, except the G.G.S. distribution and make the length equation in terms of them, with studying the effect of the equation parameters on the length.
3. Making the calculations according to sealed chamber with limited dimensions instead of infinite length chamber, studying all the effects that could be influence such as the walls of the chamber, and obtaining an equation for displacement which is suitable for this limited chamber under mentioned effects.
4. Comparing the results of the length that have been estimated theoretically with other estimated practically.

References

[1] Coulson J. M., Richardson J. F., *Chemical Engineering- Volume 2*, 3rd Edition, Pergamon Press, New York, 1978.

[2] Nonhebel G., *Gas Purification Processes for Air Pollution Control*, 2nd Edition, Butterworth and Co. (publishers), Ltd, 1972.

[3] Perkins H. C., *Air Pollution*, McGraw-Hill, Inc., 1974.

[4] Cheremisinoff P. N., Young R. A., *Air Pollution Control and Design Handbook-Part 1*, Marcel Dekker, Inc., 1977.

[5] Adapted from Course 107 (Basic Air Pollution Control Equipment) of the California Air Resources Board Compliance Division's Uniform Air Quality Training Program Manual, *Control of Particulate*, an article published at the site http://www.seattle.battelle.org/forscom/science/particulate.htm, 2001.

[6] Wilson W., *et al.* Sulphates in the Atmosphere. Paper No. 76-30.06, 69th Annual Meeting of the Air Pollution Control Assoc., Portland, Ore., U.S.A., 1976. Cited in [31]

[7] Hesketh H. E., *Understanding and Controlling Air Pollution*, Ann Arbor Science Publishers, Michigan, 1974. Cited in [31]

[8] Warner P. O., *Analysis of Air Pollutants*, John Wiley and Sons, Inc., 1967.

[9] Jacobson M., *Fundamentals of Atmospheric Modeling*, an article published at the site http://shadow.eas.gatech.edu/~kdarmenova/removal.htm, 1999.

[10] Weyssenhoff J., *Betrachtungen uber deu Gultigkeitsbereich der Stokesschen and der Stokes-Cunninghamschen Formel: Annalen der Physik,* 1920. Cited in [32]

[11] Arnold H. D., *Limitations imposed by slip and inertia terms upon Stocks' Law for the motion of spheres through liquids*, Philosophical Mag., 1911. Cited in [32]

[12] Krumbein W. C., Pettjohn F. J., *Manual of sedimentary petrography*, Appleton-Century-Crofts, 1938. Cited in [32]

[13] Irani R. R., Callis C. F., *Particle size: measurement, interpretation, and application*, John Wiley and Sons, 1963. Cited in [32]

[14] Oseen C. W., *Uber den Gultrigkeitsbereich der Stokes'schen Widerstandformel*, Arkiv for Matematik, Astronomi Fysik, 1913. Cited in [32]

[15] Rubey W. W., *Settling velocities of gravel, sand, and silt particles*, Am. J. Sci., 1933. Cited in [32]

[16] Wadell H., *Some new sedimentation formulas, physics*, 1934. Cited in [32]

[17] U. S. EPA, Office of Air Quality Planning and Standards, *Control Techniques for particulate Emissions from Stationary Sources-Volume 1*, EPA-450/3-81-005a, Research Triangle Park, NC, 1982. Cited in [33]

[18] Wark K., Warner C., *Air Pollution: Its Origin and Control*, Harper Collins, New York, 1981. Cited in [33]

[19] Corbitt R., *Standard Handbook of Environmental Engineering*, McGraw-Hill, New York, 1990. Cited in [33]

[20] Perry R., Green D., *Perry's Chemical Engineers' Handbook*, 6^{th} Edition, McGraw-Hill, New York, 1984. Cited in [33]

[21] Mycock J., Mckenna J., and Theodore L., *Handbook of Air Pollution Control Engineering and Technology*, CRC Press, Boca Raton, FL, 1995. Cited in [33]

[22] Avallone E., Baumeister T., *Marks' Standard Handbook for Mechanical Engineers*, McGraw-Hill, New York, 1996. Cited in [33]

[23] U. S. EPA, Office of Air Quality Planning and Standards, *Stationary Source Control Techniques Document for Fine Particulate Matter*, EPA-452/R-97-001, Research Triangle Park, NC, 1998. Cited in [33]

[24] Josephs D., Equipment Product Manager, AAF International, (502) 637-0313, personal communication with Eric Albright, 1999. Cited in [33]

[25] Davis W., Professor and Coordinator, Environmental Engineering Program, Department of Civil and Environmental Engineering, University of Tennessee, (423) 974-7728, personal communication with E. Albright, 1999. Cited in [33]

[26] Kumar A., *Particulate Control*, an article published at the site http://www.utoledo.edu/~aprg/courses/iap/text/part_ctrl1.html, 2002.

[27] McCabe W. L., Smith J. C., *Unit Operations of Chemical Engineering*, 2nd Edition, McGraw-Hill, Inc., 1967.

[28] Gordon G., Peisakhov I., *Dust Collection and Gas Cleaning*, MIR Publishers, Moscow, 1972.

[29] Schubert H., *Mechanische Verfahrenstechnik 1*, VEB. D.V.G., Leipzig, 1977.

[30] Holman J. P., *Heat Transfer*, McGraw-Hill Book Co., Singapore, 1989.

[31] A Report of the United Nations Economic Commission for Europe, *Fine Particulate Pollution*, Pergamon Press, 1979.

[32] Galehouse J. S., *Sedimentation Analysis*, an article published at the site http://hjs.geol.uib.no./hovedlab/analysis_sedimentation_eng.html#velocity, 2000.

[33] U. S. EPA, Office of Air Quality Planning and Standards, *Air Pollution Technology Fact Sheet,* an article published at the site http://ceenve.calpoly.edu/cota/jscript/fsettlng.pdf.

Appendix A

Appendix A-1

```
clc
% g=gravity acceleration(m/s^2);
g=9.81;
% A=height of chamber(m);
A=   ;
% nt=maximum of diameter range(micron);
nt=900;
h=0;
disp('    Dp       Ar        Vf       L      ');
disp('     =====     =======    =======  =======     ');
for Dp=0:50:nt;
h=h+1;
%     dynamic viscocsity=1.845e-5(kg/m.s);
%     fluid density=1.2(kg/m^3);
%     vs=kinematics viscosity=(1.845e-5/1.2);
vs=1.54e-5;
%     ds=particle density(kg/m^3);
ds=2650;
%     vg=gas velocity(m/s);
vg=   ;
Ar=((((Dp*(1e-6)).^3)*g*(ds-1.2))/((vs).^2)*1.2);
if Ar <9;
Lj=((1/18)^3)*((Ar)^2);
end
if Ar >9 & Ar <325;
Lj=((0.0815)^3)*((Ar)^1.5);
end
if Ar >325 & Ar <1.07e4;
Lj=((0.1623)^3)*((Ar)^1.143);
end
if Ar >1.07e4 & Ar <3e5;
Lj=((0.3115)^3)*((Ar)^0.875);
end
if Ar >3e5 & Ar <3e9;
Lj=((1.73)^3)*((Ar)^0.5);
```

```
end
Vf=((Lj*vs*g*(ds-1.2))/1.2).^0.33;
L=(A*vg)/Vf;
disp([Dp,Ar,Vf,L]);
end
```

Appendix A-2

```
clc
% parameter=x1=x80/3
x1=  ;
% parameter=k
k=  ;
% height of chamber(m)=h
h=  ;
% velocity of gas(m/s)=vg
vg=  ;
disp('    p           L    ');
disp('      =====       ===== ');
m=0;
% distribution function=p=H(x)
for p=0.1:0.1:1;
m=m+1;
c=1.037+27.07/(h)^1.11;
x(m)=x1*(p/.8)^1/k;
L(m)=(7.55-3.37*(h)^.47-5.4*(vg)^1.35+(-
22.2+9.4*(h)^.63+43.3*(vg)^1.23)/x(m)^.24+(3057+2794*(h)^1.1+196857*(
vg)^.94)/x(m)^2)/c;
disp([p,L(m)]);
end
```

شكر و تقدير

أود أن أعبر عن إمتناني العميق و شكري الجزيل لمشرفي الاستاذ الدكتور محمد نصيف لما بذله من جهد كبير و إرشادات سديدة و قيمة طوال فترة إعداد الرسالة.

أود أيضاً أن أشكر السيد رئيس القسم و موظفي قسم الهندسة الكيمياوية لتعاونهم أثناء فترة البحث.

و الشكر الجزيل إلى عائلتي لما أبدوه من دعم و تشجيع طوال فترة البحث.

م. أحمد شامل عبد الرحمن

الخلاصة

تم الحصول على معادلة لحساب المسافة المحتاجة للترسيب من قبل جزيئة غبار معلقة في الغاز والذي يؤخذ كهواء بدلالة ارتفاع الحجرة، سرعة الهواء، وقطر جزيئة الغبار. هذه المسافة المقطوعة من قبل جزيئة ذات قطر معين تمثل أيضا أقصى طول للحجرة تترسب عنده نفس الجزيئة وبنفس القطر أما الجزيئات ذات الاقطار الاكبر فسوف تسقط خارج الحجرة والجزيئات ذات الأقطار الأصغر فسوف تسقط داخل الحجرة.

الحجرة هنا مفروضة على أنها ذات طول غير منتهي ولا توجد جدران لتحدها وتؤثر فيها والسيطرة تتم على ارتفاعه وسرعة الغاز اللذان سوف يفرضان.

بصورة عامة هناك ثلاثة عوامل تؤثر على طول الحجرة وهي ارتفاع الحجرة، سرعة الغاز، وسرعة الترسيب وبالتالي دراسة هذه التأثيرات مهمة من أجل الحصول على معادلة الطول أو المسافة وتأثيرات هذه العوامل تتلخص إما بأخذ قيم مختلفة مفروضة من طول الحجرة مع قيمة ثابتة مفروضة من سرعة الغاز أو بأخذ قيم مختلفة مفروضة من سرعة الغاز مع قيمة ثابتة مفروضة من طول الحجرة بينما يتم الحصول على قيم مختلفة من سرعة الترسيب عن طريق تعويض قيم مفروضة من القطر في معادلات معينة لحساب سرعة الترسيب. بالنتيجة يتم الحصول على قيم مختلفة من الطول في كلتا الحالتين واللتان يتم تمثيلهما بمعادلتين مختلفتين. يتم هذا كله بواسطة برنامج حاسوبي.

معدل ألخطأ في معادلة سرعة الغاز الثابتة ومعادلة طول الحجرة الثابتة هو بالتتابع 5٪ ، 4,9٪.

للحصول على معادلة واحدة عامة يمكن إستعمالها في جميع الحالات تم جمع معادلتي سرعة الغاز الثابتة وطول الحجرة الثابتة. معدل الخطأ في المعادلة الناتجة هو 16,7٪.

تم الحصول أيضا على معادلة لحساب المسافة المحتاجة للترسيب بدلالة معادلة التوزيع الإحصائي للمساحيق مع دراسة تأثير حدود معينة موجودة في معادلة الإحصاء على معادلة الطول أو المسافة.

فصل الجزيئات من الهواء باستخدام حجرة الترسيب

رسالة

مقدمة إلى كلية الهندسة في جامعة النهرين وهي جزء من متطلبات نيل

درجة ماجستير علوم في الهندسة الكيمياوية

من قبل

أحمد شامل عبد الرحمن البزاز

(بكالوريوس في الهندسة الكيمياوية ٢٠٠١)

شعبان ١٤٢٥هـ

تشرين الاول ٢٠٠٤م