Pore Size and Porosity in Packed Bed
Using RRSB Distribution

A Thesis
Submitted to the College of Engineering
of Nahrain University in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
in
Chemical Engineering

by

Suha Mahdi Saleh
(B.Sc.in Chemical Engineering 2003)

Jamada Al-Awal	**1427**
June	**2006**

CERTIFICATION

I certify that this thesis entitled **"Pore Size and Porosity in Packed Bed using RRSB Distribution"** was prepared by **Suha Mahdi Saleh,** under my supervision at Nahrain University/ College of Engineering in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering.

Signature: Latif

Name: **Dr. Mohammed .N.Latif**

(Supervisor)

Date: 18 / 5 / 2006

Signature: Q.M.S Slaiman

Name: **Prof. Dr. Qasim J. Slaiman**

(Head of Department)

Date: 18/7/ 2006

CERTIFICATE

We certify we have read this thesis, entitled " **Pore Size and Porosity in Packed Bed using RRSB Distribution**" and as examining committee examined the student **Suha Mahdi Saleh** 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: Latif
Name:Dr.Mohammed.N.Latif
(Supervisor)
Date: 18 / 7 /2006

Signature: Thamer J.M
Name:Dr.Thamer.J.Mohammed
(Member)
Date: 9 / 7 / 2006

Signature: Wadood
Name:Dr.Wadood .T.Mohammed
(Member)
Date: 21 / 6 / 2006

Signature: J. Shanshool
Name : Prof.Dr.Jabir Shanshool
(Chair main)
Date: 29/ 6/06

Approval of the College of Engineering

Signature:
Name:Prof. Dr . Fawzi M. AL .Naima
Dean of the College of Engineering
Date: / /

M. J. Jweeg
Prof. Dr. Muhsin J. Jweeg
Acting Dean
14-8-2006

ABSTRACT

The aim of this research is to study pore size and porosity theoretically and experimentally in order to study the proprieties of packed bed .

There are different types of distribution

1. Log .Normal distribution.
2. RRSB-distribution.
3. GGS-distribution.
4. Rinkes- distribution.
5. PM- distribution.

RRSB distribution used in this research ,in order to get number percent used in theoritcal and experimental part.

$$H_3 = 1 - \exp\left[-\left(\frac{d}{d_{63/3}}\right)^n\right]$$

In this research ,the mean pore diameter and the probability of pore diameter due to (number, length, surface area and volume) was found by using theoretical method suggested by Latif .

Experimentally packed bed was made by putting five types of spheres diameters (d1=6,d2=8,d3=10,d4=20,d5=26 mm) inside glass cylinder D=12.9 cm consists of sieve has pores of diameters 4 mm in bottom and then three kinds of impurities of diameters (A=1.2-2 , B=2-2.36, C=2.36-3 mm) passed through the packed bed ,the percent output of impurities and porosity was found in two ,three and four layers .It's noticeable from experimental result that the percent output of impurities and porosity decreased with the increase of number of layers also the percent output of impurities decreased with the increase the size of impurities .

Experimental results are related with theoretical results in order to find the relation between mean pore diameter and percent output of impurities and porosity for each number percent of beds ,the increase in size of spheres lead to increase the mean pore diameter .

Also in this research porosity was found theoretically and experimentally .Firstly porosity for mono system was calculated by using

Furnas equation and then determined experimentally in each experiment one kind of sphere used these spheres (d1=6,d2=8,d3=10,d4=20,d5=26 mm) putting known number of spheres inside cylinder glass D=12.9 cm and measure the height of the spheres in the cylinder to find the volume of bed in order to find the porosity .The same procedure repeated for cylinder D=6.4 cm. It is noticeable from theoretical and experimental results that the porosity increased with increase the diameter of spheres. and decreased with increase the diameter of the bed contain the spheres.

Theoretical results compared with experimental results firstly in cylinder of D=12.9 cm and found the absolute error range 0.3% & 2.59 %. Furnas equation modified under consideration the present work .

$$\varepsilon_f = 0.38017 + 0.3458\left(\frac{d}{D}\right) \quad \ldots\ldots (4.2)$$

$$\varepsilon_f = 0.3475 + 1.406\left(\frac{d}{D}\right) - 9.86\left(\frac{d}{D}\right)^2 + 27.11\left(\frac{d}{D}\right)^3 \ldots\ldots\ldots\ldots (4.3)$$

The absolute error in cylinder of D=6.4 cm lies between 1.86 % & 4.16 %. Furnas equation modified under consideration the present work .

$$\varepsilon_f = 0.38829 + 0.3319\left(\frac{d}{D}\right) \ldots\ldots\ldots (4.5)$$

$$\varepsilon_f = 0.33318 + 1.406\left(\frac{d}{D}\right) - 9.86\left(\frac{d}{D}\right)^2 + 27.11\left(\frac{d}{D}\right)^3 \ldots\ldots\ldots (4.6)$$

Porosity for binary system was calculated theoretically by using Jeschar equation and Latif equation .Then determined experimentally by putting known number of two kinds of spheres (d1=26,d2=6mm) (d1=20,d2=6mm),(d1=10,d2=6mm),(d1=8,d2=6mm),(d1=26,d2=8mm),(d1=20,d2=8mm)(d1=10,d2=8mm),(d1=26,d2=10mm),(d1=20,d2=10mm) ,(d1=26,20mm) in glass cylinder of D=12.9 cm and measure the height of the spheres in the cylinder to find the volume of bed in order to find the porosity. Theoretical results compared with experimental results and found the absolute error in Jeschar is low equation range 4.85% to 17 % but in Latif equation absolute error is high its range from 0.985% to 68.3% . Then Latif equation modified under consideration the present work absolute error found its range 0.04% to 13.8% .

$$\varepsilon_f = \left(0.45488 + 0.05466 v_2\right)\left(\frac{d_2}{d_1}\right)^{0.1283 - 0.04068 v_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4.7)$$

CONTENTS

NOTATIONS

a_k	Ratio between diameter of small and large particle.
a_m	Ratio between diameter of medium and large particle.
A_g	Area function of large spheres.
A_k	Area function of small spheres.
A_m	Area function of medium spheres.
A	Area (cm^2) .
d	Particle mean diameter (mm).
dc	Mean value of pore diameter (mm).
dc_I	Pore diameter of three equal sizes of diameter (mm).
dc_{II}	Pore diameter of two equal and one different sizes of diameter (mm).
dc_{III}	Pore diameter of three different sizes of diameter (mm).
$dc_m a$	Mean pore diameter due to area .
$dc_m I$	Mean pore diameter due to length .
$dc_m n$	Mean pore diameter due to number .
$dc_m v$	Mean pore diameter due to volume .
d_g	Large particle diameter (mm).
d_k	Small particle diameter (mm).
d_m	Medium particle diameter (mm).
D	Diameter of the container (cylinder) (mm).
$d_{63/3}$	Diameter at H_3 =63.3 %
H_3	Cumulative distribution
K	Single phase permeability , (cm^2) .
K_1 to K_2	Constants.
L_g	Length function of large spheres.
L_k	Length function of small spheres.
L_m	Length function of medium spheres.
L	Height of the sphere in the bed (mm).
n	Number of repetitions.
n_g	Number of repetitions of large spheres.
n_k	Number of repetitions of small spheres.
n_m	Number of repetitions of medium spheres.
N_g	Number function of large spheres.

$\mathbf{N_k}$	Number function of small spheres.
$\mathbf{N_m}$	Number function of medium spheres.
N	Number of the sphere in the bed.
n	
P	Pressure,atm.
$\mathbf{P_i}$	Probability of finding the pores.
$\mathbf{P_r}$	Probability for diameters.
$\mathbf{P_{ra}}$	Probability of diameters due to area.
$\mathbf{P_{rl}}$	Probability of diameters due to length.
$\mathbf{P_{rn}}$	Probability of diameters due to number.
$\mathbf{P_{rv}}$	Probability of diameters due to volume.
Q	Surface tension dyne/cm.
r	Type of distribution.
$\mathbf{r_g}$	Type of distribution for large particles.
$\mathbf{r_k}$	Type of distribution for small particles.
$\mathbf{r_m}$	Type of distribution for medium particles.
So	Specific surface ,(cm^2/ cm^3)
$\mathbf{V_g}$	Volume function of large spheres (cm^3).
$\mathbf{V_k}$	Volume function of small spheres(cm^3) .
$\mathbf{V_m}$	Volume function of medium spheres (cm^3).
V	Volume of the void (cm^3) .
$\mathbf{V_T}$	Total volume(cm^3) .
$\mathbf{V_P}$	Volume of the particle (cm^3) .
ε	Porosity .
ε_o	Average value of porosity between ε_1 and ε_2.
$\boldsymbol{\mu}$	Viscosity,cp.

ABBREVIATIONS

RRSB Rosin,Rammler,Sperling,Bennett.
GGS Gates,Gaudin,Schuhmann
PM Prerorska,Misek.
PBR Packed bed reactor
PSM Pore size meter
LC Liquid chromatography

Tables

FIGURES

CHAPTER ONE

INTRODUCTION

The study of pore size and porosity is necessary to study the packing. The packing of particles is of great interest in a variety of scientific technological areas. These includes, for example ,catalytic reactors, packed absorption, distillation towers , packed filter ,ceramics , concrete, powder metallurgy ,tabling and others(1,2,3,4).

The work with catalysts, ceramics pharmaceuticals, carbons, building materials or with any other porous or divided solid needs quantitative information about pore size (5).

Pore size parameters may be used to predict with confidence the in service performance of these construction materials .Illustrations of progress in this direction have been presented for hydrated Portland cement ,concrete aggregates, compacted fine grand soils and embankment shale's(6).

The unsaturated hydraulic conductivity of arouse sediment varies with capillary pressure which in turn depends on the complex arrangement of pore within the sediment .Present theories indicate that un saturated conductivity is systematically related to the distribution of pore size(7).

The need to improve the quality of mathematical simulations in such diverse fields as per collation, diffusion, and chemical reaction in catalysts requires the inclusion of statistic description of pore size distribution (8).

Treating pores of various diameters as uniform in size e.g. average pore diameter (pore size distribution)tends to understanding the plugging effect of small pores by enzyme molecules during immobilization process especially for porous solids with broad or bimodal pore size distribution(9).

Pore size plays dominate role in transport phenomena e.g. a number of seemingly comparable phenomena concepts are discussed drainage - imbibitions suction mercury ,porosimestry, molecular diffusion, viscous flow, capillary potential(10).

Among the more promising uses of pore size distribution data is the explanation and ultimately the prediction of water permeability of compacted soils (11).

In addition to the pore size porosity is one of fundamental properties of abed of particulate materials. Indication of porosity value have wide significance in a number of industrial applications such as :

1-Powder metallurgy.
2-Concrete production.
3-Ceramics.
4-Packing and transport.

The aim of this research is :-

1-Description of pores using spherical particles.
2-Calculate the probability of the pore diameter due to different particle size distribution (number ,length ,area, and volume) in different number of packing layers.
3-Weight percent of output impurities in two, three and four layer .
4-Determine the porosity in two, three and four layer.
5-Calculate porosity for mono system sphere by using Furnas equation and also determined experimentally then derive empirical equation for mono system .
6-Calculate porosity for binary system by using Jeschar equation and Latif equation and also determined experimentally then derive empirical equation for binary system .

The above steps is necessary in many of the industrial process need to calculate the pore size and porosity in packing in order to purify materials from impurities .Sedimentation process and separation of one material from another require the calculation of the particles diameters which pass through the pores that are formed in the packing particle.

CHAPTER TWO

LITERATURE SURVEY

2.1 Porous Media

A analysis of pore structure and pore radius distribution is necessary in order to construct on effective model for a porous medium (12)

The following things are examples of porous media:-glass spheres packed sand spheres, crystalline, calcium fluoride towers packed (13). with pebbles ,beryl saddles ,crashing rings ,granules load shot, porous rocks such as limestone ,pumice dolomite etc fibrous aggregates such as cloth ,felt, filter paper and finally catalytic particles(14)

The models of a porous medium consist of lattice networks of cylindrical channels with distribution of radii and also of randomly packed rotund particles examples spheres as described by Iczkowski ,Mason and Haynes(15)

Modern theory on laminar flow of fluids in porous media dates from the research of Darcy in 1958 he study the relation ship between parameters involved and designed the motion of permeability as structural parameter.

$$Q = \frac{K}{M} . \left(\frac{p_2 - p_1}{L} \right) . A \qquad \text{............(2.1)}$$

Another land mark was Koseny-Carman equation 1937 which gives the relative permeability $K = \dfrac{\varepsilon^3}{h_k . (1-\varepsilon) . So^2}$ ....(2.2) modern theory on laminar flow of fluids (16).

The significant properties of porous media is

1-Porosity which is a measure of the pore space and hence of the fluid capacity of the medium.
2-Permeability which is a measure of ease with which fluids may traverse the medium under the influence of a driving pressure (17)

Relative permeability characteristics of a porous medium depend on the structural configuration of the void space in which flow take place.

There are different approaches have been developed for studying flow and displacement processes in disordered porous media. these approaches are (Perrine 1961,Heller1966,Whitaker 1967,Slattery 1967,Peters 1984 ,Chang and Slatttery 1986)(18).

2.1.1 Classification of Pores

Intuitively “pore” are void spaces which must be distributed more less frequently through the material if the latter is to be called “porous” void is a space between particles extremely small voids in a solid are called “molecular interstices” very large ones are called “caverns"." pore” are void space intermediate between caverns and molecular interstices the limitation of their size is there fore intuitive and rather indefinite (19)

A porous solid {solid with cavities or channels which are deeper than they are wide}consists of solid matrix and pores .The pore may be further classified as open pores, closed end pores and isolated pores .

The classification is important for example only pores of the fist two types would permit the diffusion of a gas within the pores of the solid (20)

Pore classified in to open pore {cavity or channel with access to the surface} and closed bed {cavity not connected to the surface}, blind pore or dead end pore {pore with a single connection to the surface} and inter connected pore {pore which communicates with other pores}.Pore which are open at both sides of a membrane or porous plug are termed through pores.

The classification of pores according to size has been under discussion for many years ,but in the past the terms micro pore {pore of internal width greater than 2 mm}.Macro pore {pore of internal width greater than 50 mm}.has been applied in different ways by physical and chemists and some other scientists in an attempt to clarify this situation .Mesopores{pore of internal width between 2mm and 50 mm}are especially important in the context of adsorption.

Pore size is generally specified as the pore width has a precise meaning when geometrical shape is well defined nevertheless for most purposes the limiting size is that of the smallest dimension and this is generally taken to represent the effective pore size.(21)

2.1.2 Pore Structure

Pore structure is modeled by using information about the pore size distribution that determines the capillary pressure.

The pore structure of un consolidated media as well as natural sandstones can in large be characterized in terms of pore size shapes, distribution and topology (12).

Pore structure implicitly presents in most of the proposed mechanisms of liquid movement in solid .A summary of these mechanisms as a quoted by Peck and Wasan in 1974 is

1- Liquid diffusion due to difference in moisture concentrations.
2- Liquid movement due to capillary pressure forces.
3- Vapour diffusion in partly air –filled pores due to differences in partial pressure.
4- Liquid or vapour flow due to differences in total pressure, generated by external pressure capillarity, shrinkage or high temperature inside the moist materials.
5- Liquid movement due gravity (22).

2.2 Co ordination Number

The contacts between spheres are fundamental feature of packing which condition the mechanical stability and transport properties in the solid phase (23).

Co ordination number is the number of contact points on a particle in multi component packed bed with size distribution had been obtained by Arakawa and Nishino and Powell from experiment or computer simulation but these data obtained for only or two particular types of size distribution and did not compare with the model or theoretical equations.

The computer simulation were developed for three components randomly Packed bed. And studied the relation between co ordination numbers and size distribution these are log-normal, log uniform rosin

Rammler and Andreasen .The reason of using computer program simulation because it is difficult to measure the co ordination number in packed bed with size distribution experimentally (24).

The average co ordination number is close to 6 whatever the size distribution because the stability criterion and precisely to the three contact position each new practice creates 6 contacts 3 for itself and 1 for each of the 3 supporting particle so expect for the top and bottom particles which are not analyzed(25).

Co ordination number depends on the definition of a contact for which three cases are usually identified) (23):

1- Contact co ordination when sphere really touch one another.
2- Close co ordination when spheres are with in a short distance of one another say 10% of inters center distance.
3- Neighbour hood co ordination when spheres are separated by about $\sqrt{2}$ (r1+r2).

Kissing number the number of equivalent hyper spheres in *n* dimensions which can touch an equivalent hyper sphere with out any intersections also sometimes called the Newton number, contact number, co ordination number.

Eric Weisstein correctly believed that the kissing number in three dimensions was 12 but the first proofs were not produced until the 19th century {Conway and Sloane 1993, p.21}by Bender 1874, Hoppe 1874 and Gunther Leech 1956 .after packing 12 spheres around the central one and the free space not enough to fit a 13th sphere(26).

Many scientist have investigated the co ordination number of the packing of the spheres, such as smith and Foote 1929,Bennete and brown 1940 Gary 1959 Scott 1962 Clark 1965 Ridgeway and Tarbuk 1967 and Taradel and Bidean 1986 they used different techniques in their investigations to obtain the co ordination number(27),(28).

2.3 Filtration

Filtration is the physical or mechanical process of cleansing fluid where by particles in a fluid are captured, retained, or trapped during the passage of the fluid through porous media. (29).

The size of the openings in a filter or pore size determines what particles get trapped and which ones slip through (30).

Pore size rating is the pore size of the filter determined by the diameter of the particle that it can be expected to retain with a defined high degree of efficiency (31)

Filtration efficiency and pressure drop are key properties depending on a pore size distribution (32).

2.4 Sphere Packing Problem

The classical sphere packing problem is to find out how densely a large number of identical sphere can be packed together .We know that the sphere do not fit together there is always some wasted space in between(33).

Cracking Keplers solved sphere packing when he noticed that the familiar's piles of neatly stacked oranges at supermarket represent a practical solution to this problem.

When super market personal stack oranges the bottom layer consists of rows that are staged by a half an orange placing oranges in the hollows formed by three adjacent oranges .In the first produces the second layer and so on such as arrangement is known as face –centered cubic packing(34).

The assertion has long remained with rigorous proof but in august 1998 proof. Thomas hales of the university of Michigan announced a computer based solution this proof is contained in over 250 manuscript pages and relies on over 3 gigabytes of computer files and so it will be some time before it has been rigorously by the scientific community to ensure that the Kepler conjecture is indeed proven (35).

2.4.1 Packing of Sphere

The first study of spheres packing aimed to describe the structure of liquids and dealt with equal spheres. Then the packing of spheres was used to analyze the properties of granular materials .e.g., from the view point of percolation theory .the present work was carried out to study the liquid –phase sintering processes by using computer method for random packing of spheres of unequal size .this packing is built under gravity particle by particle (25).

An important property of multi particle systems is the packing density .this is defined as the volume fraction of system occupied by solids (36).

The important aspect is the structure of packing we distinguish between ordered structures. Also called a periodic or lattice arrangement is one in which the centers of the sphere form very symmetric pattern called lattice.

In two dimensional Euclidean space German mathematician Carl Friedrich gauss proved that the regular arrangement of circle with the highest density is the hexagonal packing arrangement the density of this arrangement is $\frac{3.14}{\sqrt{12}}$ =0.9069.

Disordered structure (irregular or random packing of spheres) packing of differently sized .Disordered structures are more important in practice but the order structure are more interesting for understanding of fundamental mechanisms because they allow theoretical calculation.

Arrangements in which the sphere are not arranged in lattice are called irregular or periodic arrangements .Regular arrangement are easier to handle than irregular ones their high degree of symmetry makes it easier to classify them and to measure their densities(37).

Random close packing of spheres in three dimensions gives packing densities in the rang 0.06 to 0.65(Jaeger and Nagel 1992,Torquato etal.2000).Hilbert and Cohn-Vossen(1999,pp.48-50) consider a tetrahedral lattice packing in which each sphere touch four neighbors and density is $\frac{3.14\sqrt{3}}{16}$=0.3401 and cubic lattice $\frac{3.14}{6}$ =0.5236 and hexagonal lattice $\frac{3.14}{3\sqrt{3}}$=0.6046(7).in three dimensional space gauss proved that regular arrangements of sphere called cubic close packing (or face centered cubic) and hexagonal close packing in both of this arrangement surrounded by 12 sphere and the packing density $\frac{3.14}{\sqrt{18}}$=0.74048 (71).For packing in three dimensions C.A.Rogers (1958) showed that the maximum possible packing density <$\sqrt{\ }$ 18(cos^-1 $\frac{1}{3}$-$\frac{1}{3}$ 3.14)=77.963557% (le Lionnais 1983) and this result was subsequently improved to 77.844% (Lindsey 1986) then 77.836%(Muder 1988) (38).

Natural materials involve particle may depart quite considerably from true spherical shape and more over are from uniform in size .Non uniformity in size in general permits smaller particles to fill the pores between the larger particles thus resulting in a material reduction in porosity .Angularity of the grains tends to produce bridging which results in random packing and higher porosities (17).

It is only reasonable there fore to expect that spherical models as discussed before will not be entirely adequate to represent even the geometrical properties of porous media (not to speak of hydraulic ones. they will help us to under stand some of the features better, but actual correlation between grain sizes and pore sizes, as have been proposed ,is based on experimental investigations rather than on theory ,atrue understanding of the effects of course can not be obtained in this manner (39).

Theoretical and experimental studies of the effect of grain size on pore size have been conducted by Tickell, Mechem and Mccurdy(1933),Hrubisek(1941) Rosen Feld (1949)Griffiths (1952) and Gaithe (1953) Kiesskatt and Matz (1951) and Wise (1954) discussed the dependence on the grain distribution (40).

2.4.2 Packed Bed

When sphere are taken together as a packed bed there is no way of knowing from first principles such important properties as mechanical strength of packing its thermal conductivity and its permeability to fluids these properties depend on the way the particle fit together to form a continuous solid structure and corresponding void structure (24).

Chemical engineers know this as a packed or porous bed .ground water hydrologists call this flow through porous media .They provide two methods the Idelchik and Darcy's law .The Idelchik method is valid for laminar or turbulent flow through the bed while Darcy's law is valid only for laminar flow (Darcy Reynolds number <10).another difference is that only Darcy's law requires .entering the permeability (41) .

Liquid chromatography makes use of a packed bed of spherical particles in order to separate a mixture of un known compounds (42).It separate according to the pore size .Only molecules that are smaller than the pore size can enter the pores. In a packed bed adsorption very large pore size or macro porous adsorbents can provide high efficiency (43).

The effect of pore size in packed bed reactor (PBR). PBR having the largest pore size benefited from the recirculation (44).

2.5 The Methods of Determination of Pore Size Distribution.

The ratio of pore volume to specific surface area Vp/a has been used for many years as a simple means of characterizing the pore size (21).

The conventional method of determining pore size in the nitrogen adsorption method from plotting of nitrogen adsorption data versus the statistical film thickness from slopes the surface area calculated and from intercept obtain the volume of meso pores .from surface area and volume the meso pore diameter is calculated .

Powder x-ray diffraction measurements determine pore size (45).

Pore size meter series PSM enables to measure pore sizes of porous materials such as ceramical filter and membranes .Permeability weighted pore size distribution calculated from wet flow curve (pressure drop vs. volumetric flow rate of the wet sample)and dry flow curve (similar to wet flow but obtained on dry sample)(32).

Pore size distribution in porous alumina bodies determined experimentally by the capsule free hot isostatic pressing technique (46).

Capillary pressure curves give pore size distribution in the packing (16).

Pore size of construction materials measured by mercury intrusion porosimetry(47).

The pore size distribution of activated carbons in the range of openings below 13 mm has been determined by liquid chromatography (LC) (48).

2.6 Review of Previous Work (Pore Size)

For spherical packing, pore size is conveniently measured by pore diameter so that whenever we say "pores size "means diameter. This pore size or pore diameter represents the diameter of the particle, which may be able to pass through in the pore.

Pore size measurements have been made on a number of Indiana shale's M.Kaneuji ,D.N.Winslow and W.L Dolch 1980 and M.Surendra 1980(49,50).

Filter aids which will represent the pore diameter and impurities have been represented as spherical particles by Latif (51)

Fawaz calculated the pore size for three spheres of different size using theoretical method suggested by latif and experimentally he found the percentage output of impurities which passed through the packed bed .He found the relation between mean pore diameter and percentage out of impurirties .And the relation between mean pore diameter and packed bed composition in two methods triangle methods and in X-Y plane without triagle method (52).Omar pore size for binary system using theoretical method suggested by latif and experimentally he found the percentage output of impurities which passed through the packed bed .The weight percent plotted vs.impurities diameter and the interceptions represent the mean pore diameter(53). AL-Obaidi calculated the pore size for binary spheres system using theoretical method suggested by Latif 1981 and compared it with experimental results obtained by Kreutz(54).

2.6.1 Theoretical Method to Calculate The Pore Size

In this work we use the same procedure suggested by latif 1981 to find the pore size and the mean pore size of filter aid consisting of spheres and impurities as small spherical particles ,so the calculation procedure is as follows.

i. The diameter of the (dc_{III}) which may be able to pass through the pore, as shown in fig 2.3, which represents the general case.

$$d_{ciii} = \frac{k_4 - \left(k_4^2 - 4k_5\right)^{1/2}}{2} \times d_g \quad \ldots\ldots (2.3)$$

Where:

$$k_1 = \left[\frac{(am+1)}{(am-1)}\right]^2$$

$$k_2 = \frac{4am}{(am+1)}$$

$$k_3 = \left(a_k^2 + a_k k_2\right)^{1/2} - a_k$$

$$k_4 = (k_2 + 2k_3) \times k_1$$

$$k_5 = k_3^2 \times k_1$$

$$am = \frac{dm}{dg} \quad (=1)$$

$$a_k = \frac{dk}{dg} \quad (\leq 1)$$

ii. The diameter (dc_{II})as shown in fig 2.4.a,2.4.b may be calculated by equation 2.2.a and 2.2.b for case (a)and(b)respectively .

$$d_{ciii} = \frac{\left[\left(2a_k + a_k^2\right)^{1/2} - a_k\right]^2}{2 + 2\left[\left(2a_k + a_k^2\right)^{1/2} - a_k\right]} \times d_g \quad \ldots\ldots.(2.4.a)$$

Equation (2.2.a) is used if pore by two different sphere diameters dg=dg>dk

$$d_{cii} = \frac{\left[\left(2/a_k + a_k^{-2}\right)^{1/2} - a_k^{-1}\right]^2}{2 + 2\left[\left(2/a_k + a_k^{-2}\right)^{1/2} - a_k^{-1}\right]} \times d_k \quad \ldots\ldots(2.4.b)$$

Equation (2-2.b)is used if pore by two different sphere diameters dk=dk <dg

Where: $a_k = \frac{dk}{dg}$

iii.The diameter (d_{CI}) can be calculated by the equation written below when dc=dm=dg as in fig,2.5

$$d_{ci} = 0.155 \times d_g \qquad \ldots..(2.5)$$

To calculate the probability that the diameter dc will occur is:

$$P_i = \frac{3!}{n_g!\,n_m!\,n_k!} Pr_{dg}^{ng} \times Pr_{dm}^{nm} \times Pr_{dk}^{nk} \qquad \ldots\ldots(2.6)$$

Where $r_g + r_m + r_k = 3$

Equation (2.6) is the general equation to calculate the probability due to number, volume, length and surface area, so we must have the precent due to one of it and depend on it to find the probability due to other .In this research we depend on the number percent to find the other as follows:

1. To calculate the probability due to length:

We have the number percent of each type of diameters (d1, d2, d3, d4, and d5) and to find the percent of length as below:

$$L = (d_1 \times N_1) + (d_2 \times N_2) + (d_3 \times N_3) + (d_4 \times N_4) + (d_5 \times N_5)$$
$$L_k = (d_k \times N_k)/L$$
$$L_m = (d_m \times N_m)/L$$
$$L_g = (d_g \times N_g)/L$$

Where N: number percent

d_k ,d_m ,and dg :the choice diameters.
Then we sub L_k ,L_m and L_g in eq 2.6 to find the probability due to length.

2. To calculate the probability due to area:

$$A = \left(d_1^2 \times N_1\right) + \left(d_2^2 \times N_2\right) + \left(d_3^2 \times N_3\right) + \left(d_4^2 \times N_4\right) + \left(d_5^2 \times N_5\right)$$
$$A_k = \left(d_k^2 \times N_k\right) / A$$
$$A_m = \left(d_m^2 \times N_m\right) / A$$
$$A_g = \left(d_g^2 \times N_g\right) / A$$

Then we sub A_k ,A_m and A_g in eq 2.6 to find the probability due to area.

3. To find the probability due to volume:

$$V = \left(d_1^3 \times N_1\right) + \left(d_2^3 \times N_2\right) + \left(d_3^3 \times N_3\right) + \left(d_4^3 \times N_4\right) + \left(d_5^3 \times N_5\right)$$
$$V_k = \left(d_k^3 \times N_k\right) / V$$
$$V_m = \left(d_m^3 \times N_m\right) / V$$
$$V_g = \left(d_g^3 \times N_g\right) / V$$

Then we sub V_k ,V_m and Vg in eq 2.6 to find the probability due to volume.

$$d_{cm} = \sum_{i=1}^{n} p_i d_{ci} \text{ ....(2.7)}$$

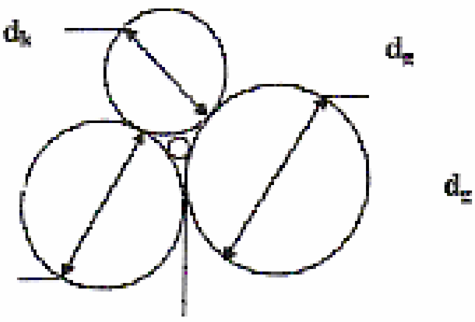

Figure 2.1 General Case.

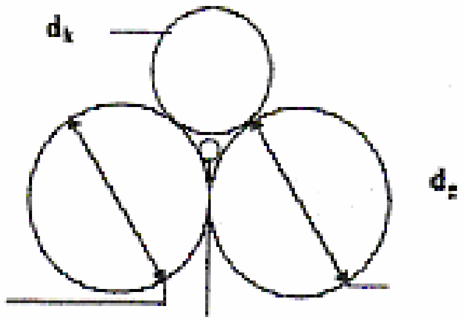

Figure 2.2 A. Pore by Two Different Sphere Diameters $d_g = d_g > d_k$

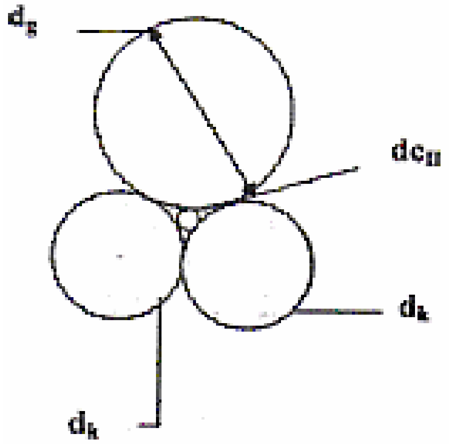

Figure 2.2 B. Pore by Two Different Sphere Diameters $d_g = d_g < d_k$

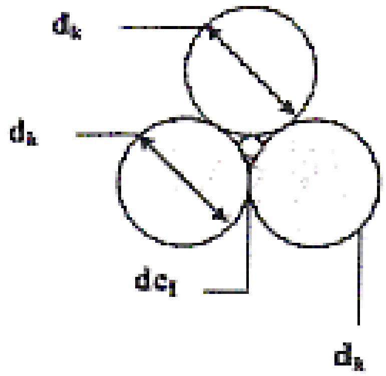

Figure 2.3 Three Equal Sphere Diameter

2.7 Porosity

The porosity is the proportion of the non-solid volume to the total volume of material, and is defined by the ratio:

$$\varepsilon = \frac{V}{V_T} \quad \text{....................(2.8)}$$

$$V = V_T - V_p$$

Where V is the non-solid volume (pores and liquid) and V_T is the total volume of material, including the solid and non-solid parts (55).

2.7.1 Review of Previous Work (Porosity)

The packing of particulate solid materials enters into most aspects of applied sciences and has there fore been studied more or less continuously for a number of years.

The first study of the modes of packing of spheres and the porosity calculated therefore appears to have been under taken by sticker in 1899 . science then the theory has been reviewed refined and extended by Smith, Foote and Busang in 1929,Gartor and Fraser in 1935,Manegold in 1937,Manegold and Solf in 1939,Hrubisek in 1941,and others(56,57,58,59) .

Several investigators (60, 61, 62, 63, 64, 65, 66) have measured the radial porosity profiles in abed packed with spheres and in abed packed with cylinders. there results were found to be similar showing fluctuation of the porosity from the wall to the center .

Ouchiyama and Tanka (67) presented mathematical model for porosity estimation from particle size distribution.

Standish and YU (68) utilized the simplex centroid design proposed by Scheffe to get mathematical model for the porosity of ternary spheres system using regression methods.

Latif(51) has farther more contributed to the prediction of porosity using experimental and statistical methods. He developed empirical equation based on discontinuous size distribution .

Rasheed(69) experimented the porosity of ternary spheres system using discontinuous size distribution .He suggested new predictive equation and compared the resulted porosity with theoretical values calculated according to empirical equations proposed by Ouchiyama(67) .

Using regression method ,AL-Azzawi(70) proposed mathematical model to find the porosity of quaternary spheres mixtures from knowledge of the weight proportions of component.

AL-Rammahi (71) produced a polynomial relation ship to calculate the porosity values from the diameter ratio {particle diameter/ bed diameter} using fitting equations for curves obtained experimentally for spheres mixture obeying RRSB size distribution.

2.7.2 Theoretical Method to Calculate The Porosity

The porosity of mono system may be calculated by Furnas equation (72) which takes care of the effect of the container wall.Furnas used in his work concrete mixture.

$$\varepsilon = 0.375 + 0.34\frac{d}{D} \qquad \text{.............} \quad (2.9).$$

The porosity for binary system may be calculated by using two equation

1. Porosity for binary system may be calculated by using Jescher equation . Jescher used in his work sphere particles.(56)

$$\varepsilon = \frac{1}{1 - x\dfrac{\varepsilon_o - 1}{\varepsilon_o . v_2}} \qquad \text{………………..}(2.10)$$

Where :

$$X = \frac{1}{1 + \dfrac{(1 - v_2)}{v_2}\left(\dfrac{d_2}{d_1}\right)^{0.6 \sin \pi v_2}}$$

2.Also may be calculated by Latif equation . Latif used in his work binary system of sphere particles the percentage weight of spheres from 0% to 25%.(51).

$$\varepsilon = (0.3994 + 0.196 v_2)\left(\frac{d_2}{d_1}\right)^{0.0283+0.9152 v_2} \qquad \text{................}(2.11)$$

CHAPTER THREE
Experimental Work

3.1 Material and Tools(pore size)

Spherical glass particles of five different sizes were used to achieve a packed bed. The density of these spheres was calculated from weight and volume of spheres and the result was listed in the table 3.1.

Table 3.1 Diameters, Density of Spheres

No.	Diameter of spheres (mm)	density (gm/cm^3)
1	6 ±	2.715
2	8 ±	2.489
3	10 ±	2.534
4	20 ±	2.489
5	26 ±	2.333

The tools used are listed below:

1. Graduated glass cylinder (fig 3.1) with height of 36.5cm, diameter of 12.9 cm , and this cylinder is opened from the top and bottom.

2. A sieve is used to retain the spheres that the packed bed consists of. it is connected to the cylinder by a resin material mixed with black cascade maker .The parts are shown in figure 3.1.

3. A digital balance (for accuracy of 0.1) was used to weight the mass of the input and output.

4. Venire with an accuracy of about 0.02 mm.

5. Blower of velocity (13000 r/min) to introduce air after putting the sizes of spheres and the impurities.

6. A small sizes of spheres was used to represented the impurities ,and these impurities are listed with their weight in table 3.2:-

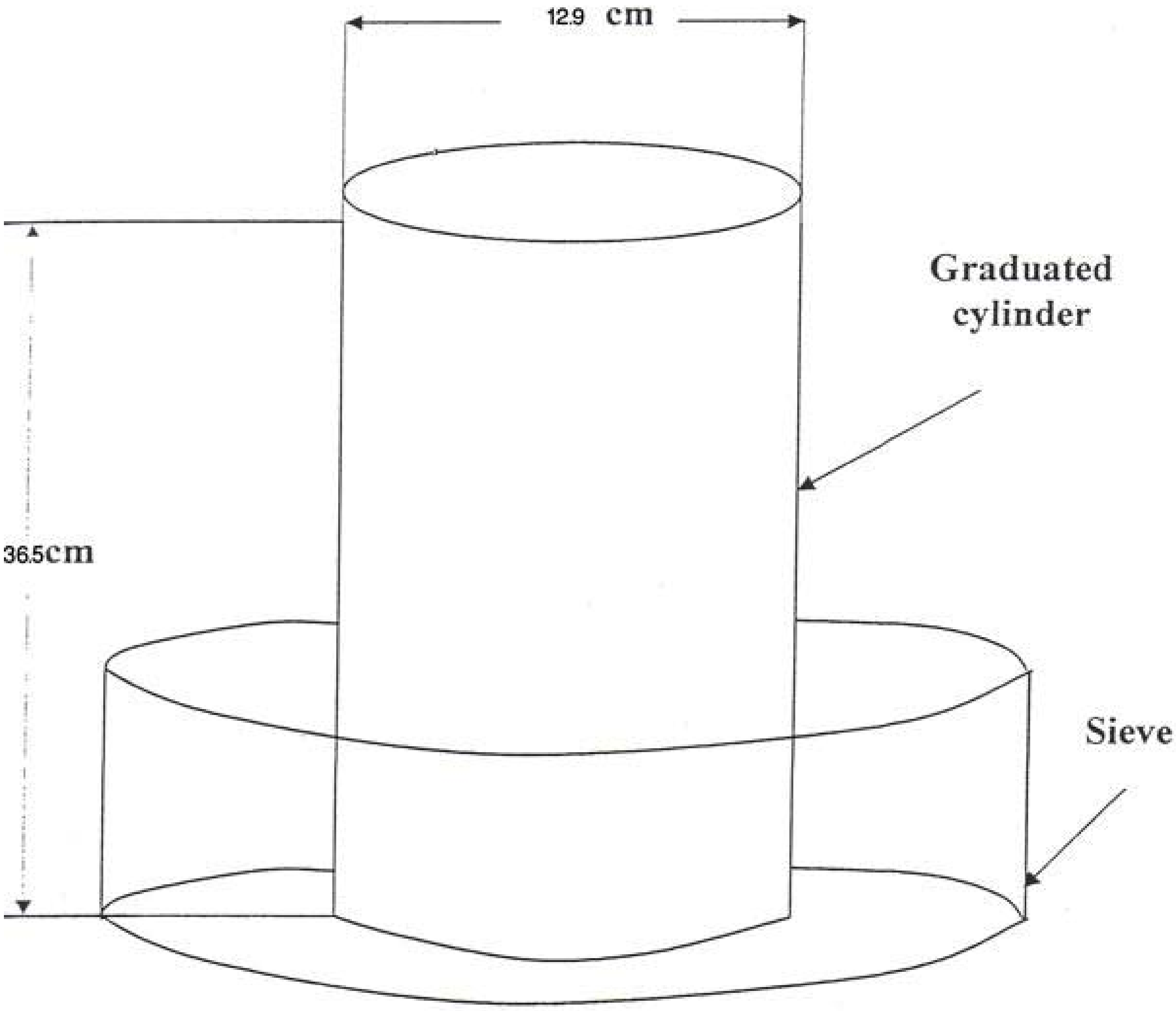

Figure 3.1 Main System of Experiment Work

Table 3.2 Diameters and Weight of Impurities.

Sample of Impurities	Diameter of Impurities(mm)	Weight (gm)
A	1.2-2	31.2
B	2-2.36	144
C	2.36-3	45.7

3.2 Procedure of Experimental Work

In each experiment, the following steps were taken:-

1.The number percent of the five sizes of spheres was chosen to make the packed bed .

2.The number of layer was chosen ,and at the beginning make two layer were chosen .

3.Acertian number of each size that had the same number percent which was chosen in step 1 are taken to make the first layer,and then put these inside the cylinder.

4. The height of packed bed of two layers was measured and calculated the porosity from equation (2.8).

5. After that, our configuration was completed and the system is ready for starting the experiment .A certain weight is taken of each sample of impurities, starting with sample "A" by entering the sample from the top of the cylinder. The blower of (13000 r/min) was used to enter air from the top of cylinder for 3 min until the system reaches the steady state (here the steady state reaches when all the spheres all the spheres stop move).The resuts of the experiments listed in appendex [C] from table C.1 to C.12

6. Taking the out put of impurities (from the bottom of the cylinder) and weights it by the digital balance.

Notice: all the above steps must be repeated for other size of impurities (B+C). Then all these steps must be repeated for three and four layers.

Experimental Work
(Porosity)

3.2 Material and Tools.

1. Graduated cylinder with diameter of 12.9cm.

2. Graduated cylinder with diameter of 6.4cm.

3. Five groups of different size spheres, the diameter and number of each group was listed in the table 3.3.

Table 3. 3 Diameters and Number of Spheres.

No.	Diameter of sphere (mm)	Number of sphere
1	6	1049
2	8	766
3	10	459
4	20	109
5	26	70

4.5 Procedure of Experimental Work

A-For Mono System

1.The spheres of diameters 6mm were packed in the cylinder of diameter 12.9 cm and height (L)of these spheres in the cylinder was measured and listed in appendix [C] table C.13 then the porosity was calculated from equation (2.8) ,and the value of porosity was listed in appendix[C] table C.14.

2. The same procedure above was repeated by using graduated cylinder of diameter 6.4 cm.

3. All steps above must be repeated for spheres 8, 10, 20 and 26 mm diameter.

B-For Binary System

1. Packed bed was made by choosing the weight percent of the two sizes of spheres. Binary system of spheres of diameters (d1=26mm,d2=6mm) were packed in the cylinder of diameter 12.9 cm and height (L)of these spheres in the cylinder was measured .The porosity was calculated from equation (2.8) .The value of the hight measured and the porosity was listed in appendix [C] table C.15.

2. The same procedure above was repeated by using another binary system of spheres(d1=20,d2=6mm),(d1=10,d2=6mm),(d1=8,d2=6mm),(d1=26,d2=8mm),(d1=20,d2=8mm)(d1=10,d2=8mm),(d1=26,d2=10mm),(d1=20,d2=10mm),(d1=26,20mm) , and the results were listed in appendix[C] tables C.16 to C.24.

CHAPTER FOUR
Results and Discussion

4.1 Presentation (pore size)

In appendix [B], the principles of theoretical work for finding the pores sizes of the packed bed ,the probabilities of finding those pores, and the mean pore diameters for each type distribution (due to number ,length ,area ,and volume).All these principles are given with detailed explanation for, and with theoretical results are listed in tables B.1 to B.25 and figures shown from 4.1 to 4.12.

In addition to theoretical work principles and their results. In chapter three experiments were done for several packed beds with different compositions in each run, and this difference due to variation in composition of small ,medium, and large spheres of which the filter aid or packed is consisted of. In each run the experiment was repeated with three sizes of impurities that were added in each experiment and the same experiments and size of impurities were repeated for two, three, and four layers and the results were given in tables C.1 to C.12.

The results of experimental and theoretical works will discuss in this chapter. These results are related to each other in away that we can study the properties of filter aid or packed bed .Also reached suitable relations about the mean pore diameter and the weight percent of output impurities. Also suitable relation between the number of layer and percent output of impurities must be found relation between the size of impurities and percent output of impurities.

Next relation between the number of layers and porosity was made. Then relations between porosity and mean pore diameter would be down.

Note: All diameters above are in mm.

Note that All the below figures are for:

$\mathbf{d_1 = 6mm, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$

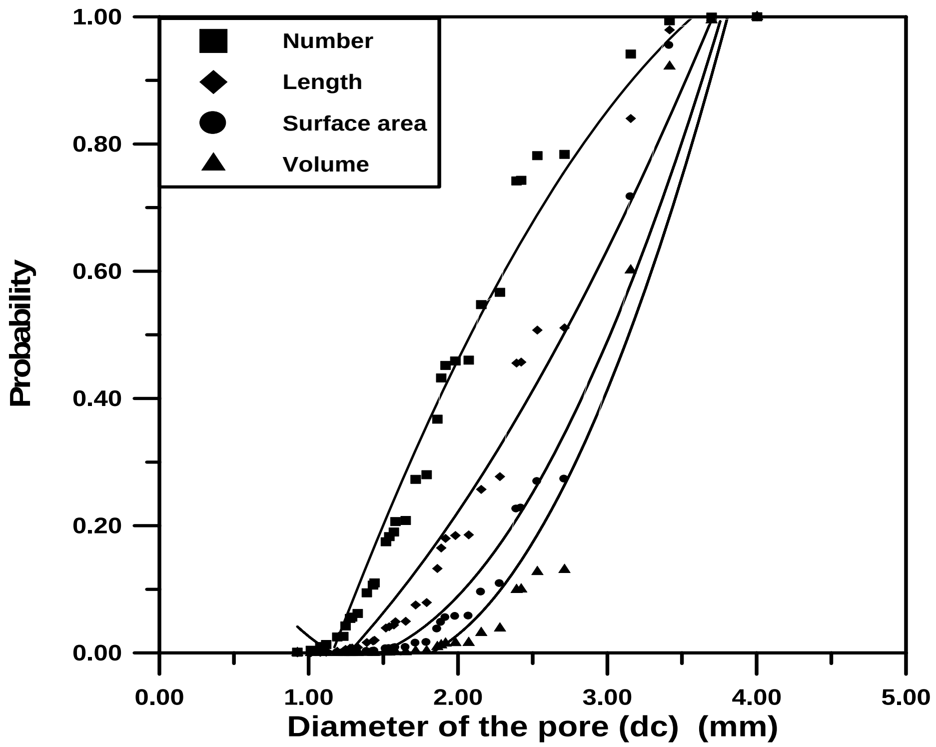

Figure 4.1 The Pore Size Distribution Due to Number, Length, Area and Volume for : $\mathbf{N_1 = 0.1, N_2 = 0.1, N_3 = 0.2, N_4 = 0.54, N_5 = 0.06}$

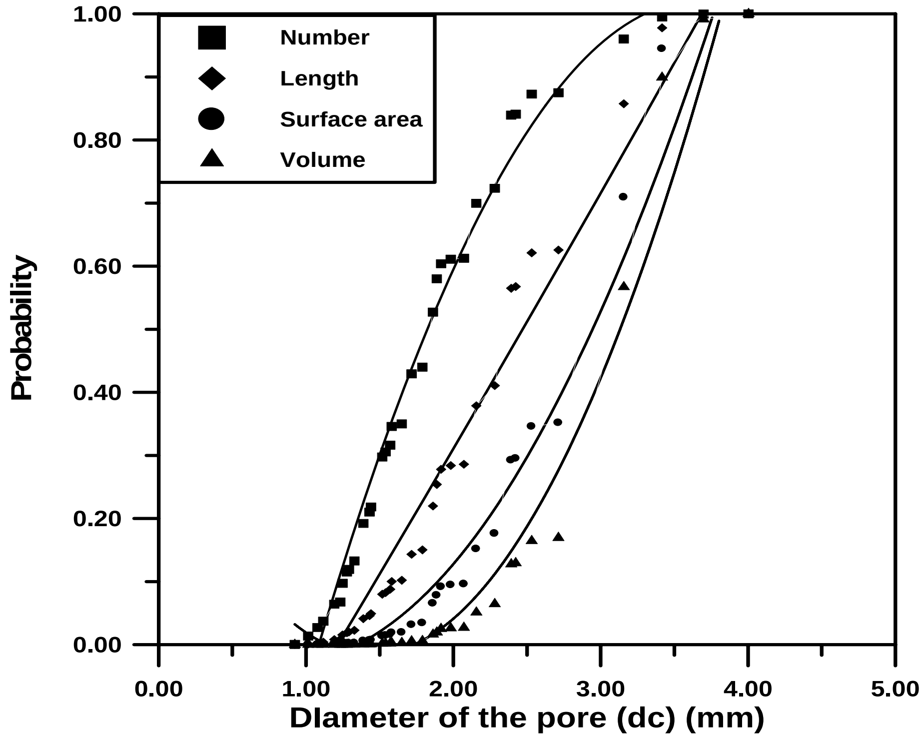

Figure 4.2 Pore Size Distribution Due to Number, Length, Area and Volume for $N_1 = 0.15, N_2 = 0.15, N_3 = 0.2, N_4 = 0.44, N_5 = 0.06$

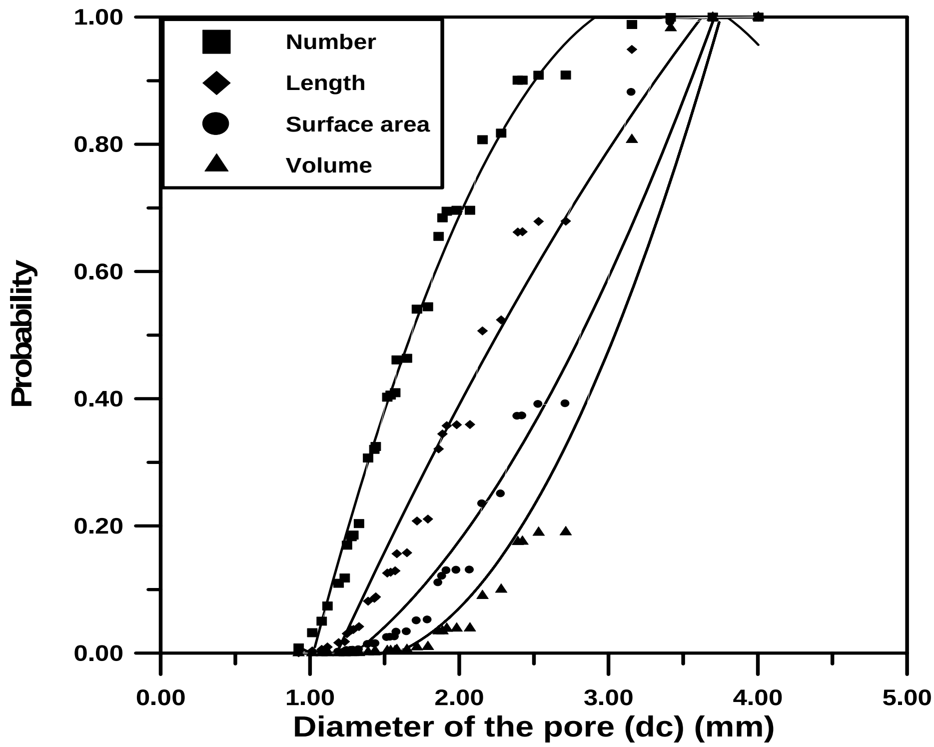

Figure 4.3 Pore Size Distribution Due to Number, Length, Area and Volume for : $N_1 = 0.2, N_2 = 0.2, N_3 = 0.15, N_4 = 0.43, N_5 = 0.02$

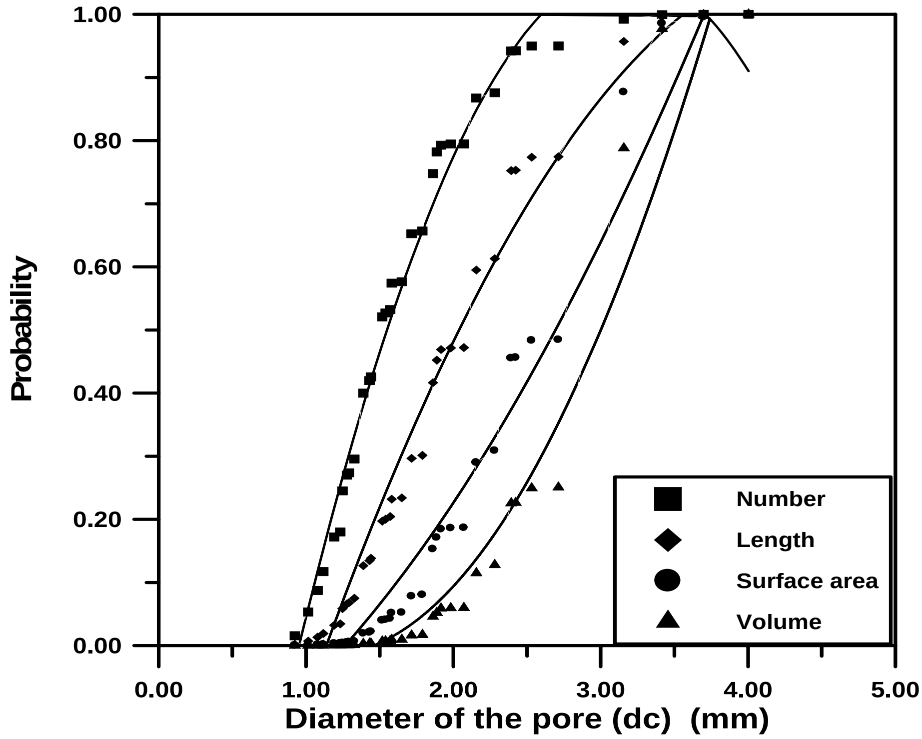

Figure 4.4 Pore Size Distribution Due to Number, Length, Area and Volume for: $\mathbf{N_1 = 0.25, N_2 = 0.2, N_3 = 0.182, N_4 = 0.348, N_5 = 0.02}$

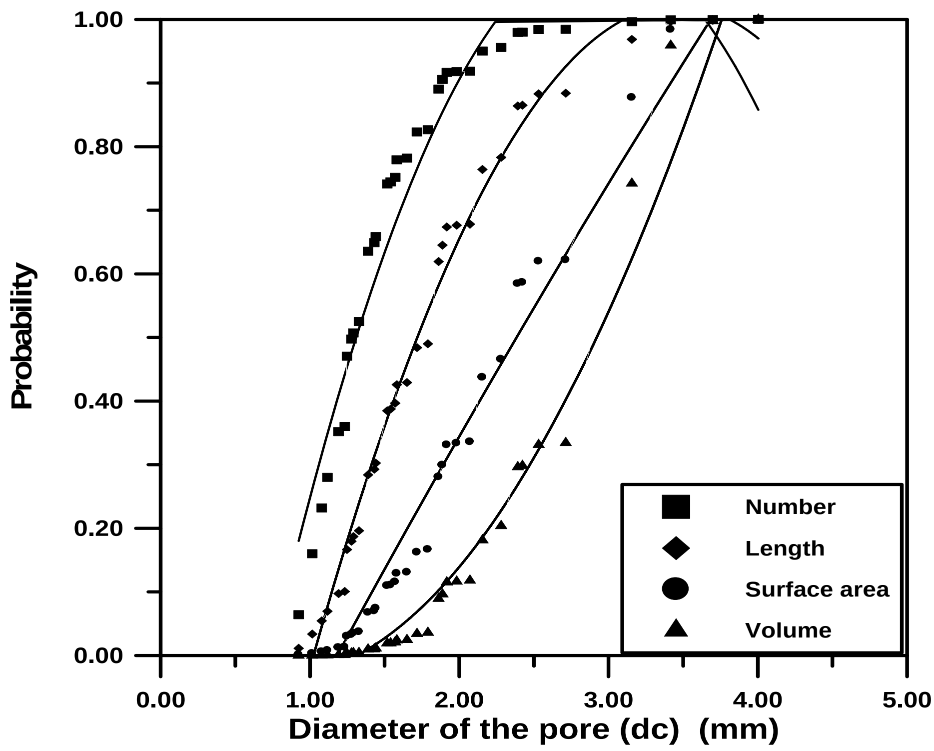

Figure 4.5 Pore Size Distribution Due to Number, Length, Area and Volume for: $\mathbf{N_1 = 0.4, N_2 = 0.2, N_3 = 0.15, N_4 = 0.23, N_5 = 0.02}$

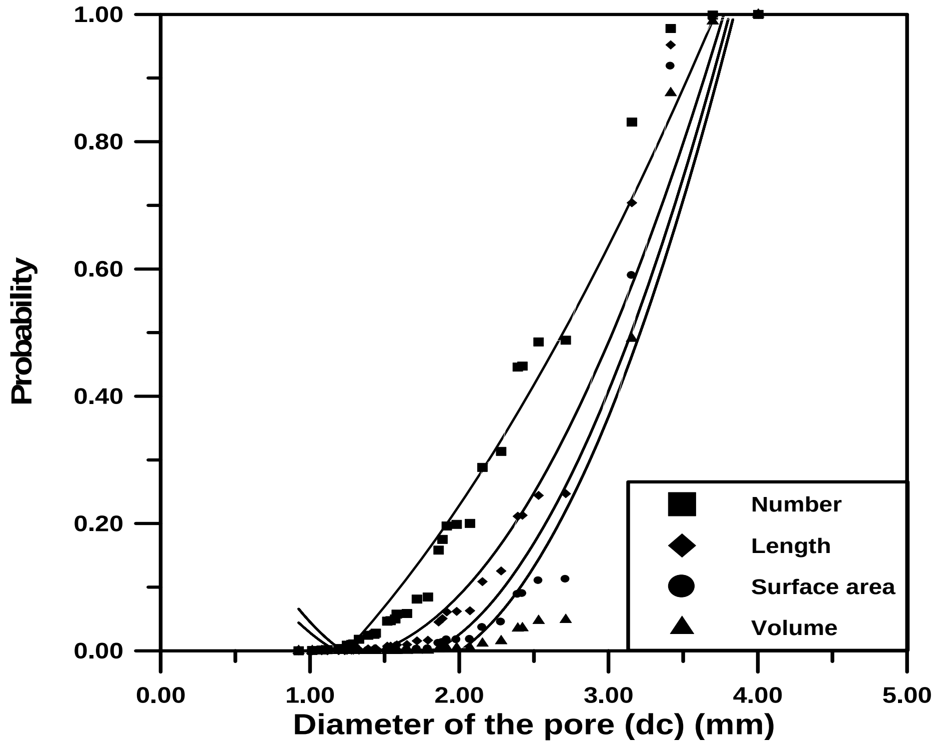

Figure 4.6 Pore Size Distribution Due to Number, Length, Area and Volume for: $N_1 = 0.05, N_2 = 0.06, N_3 = 0.09, N_4 = 0.7, N_5 = 0.1$

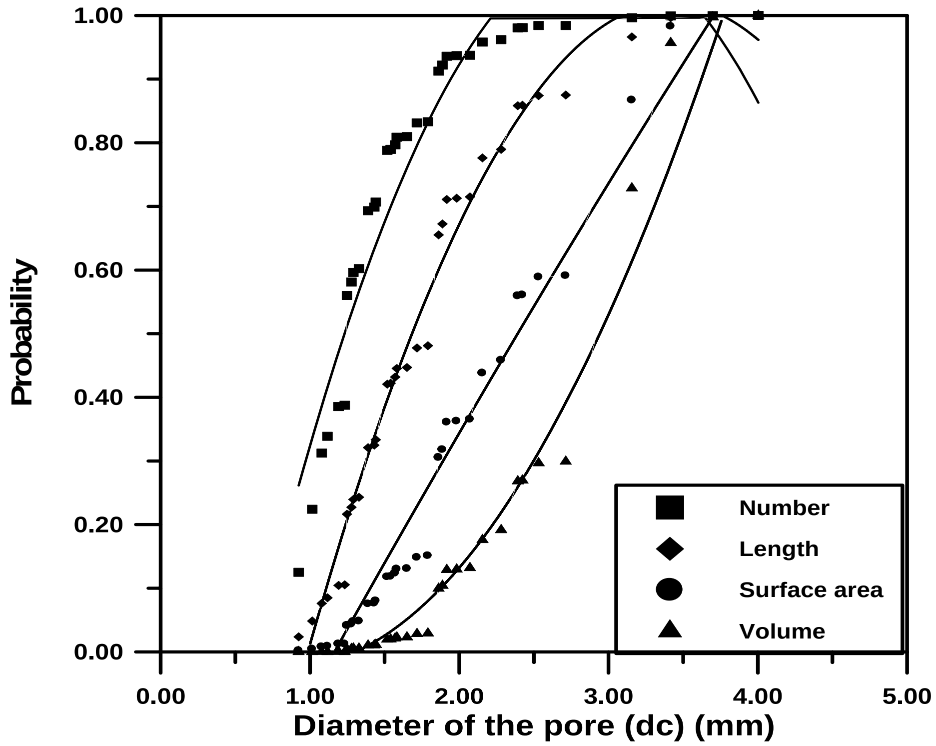

Figure 4.7 Pore Size Distribution Due to Number, Length, Area and Volume for: $N_1 = 0.5, N_2 = 0.132, N_3 = 0.118, N_4 = 0.23, N_5 = 0.02$

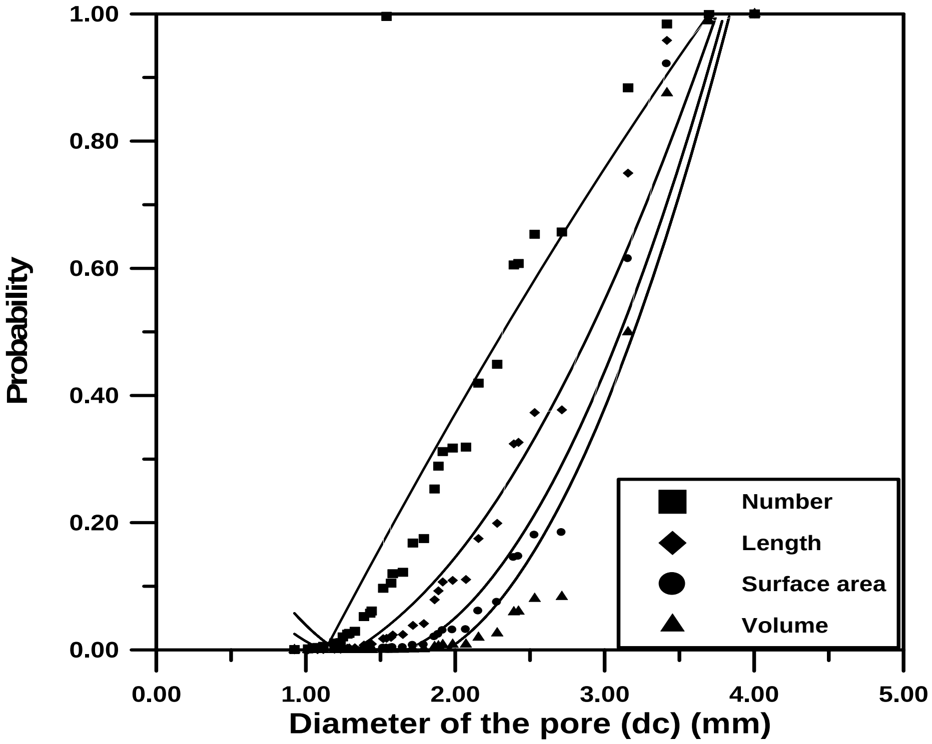

Figure 4.8 Pore Size Distribution Due to Number, Length, Area and Volume for $N_1 = 0.07, N_2 = 0.09, N_3 = 0.14, N_4 = 0.61, N_5 = 0.09$

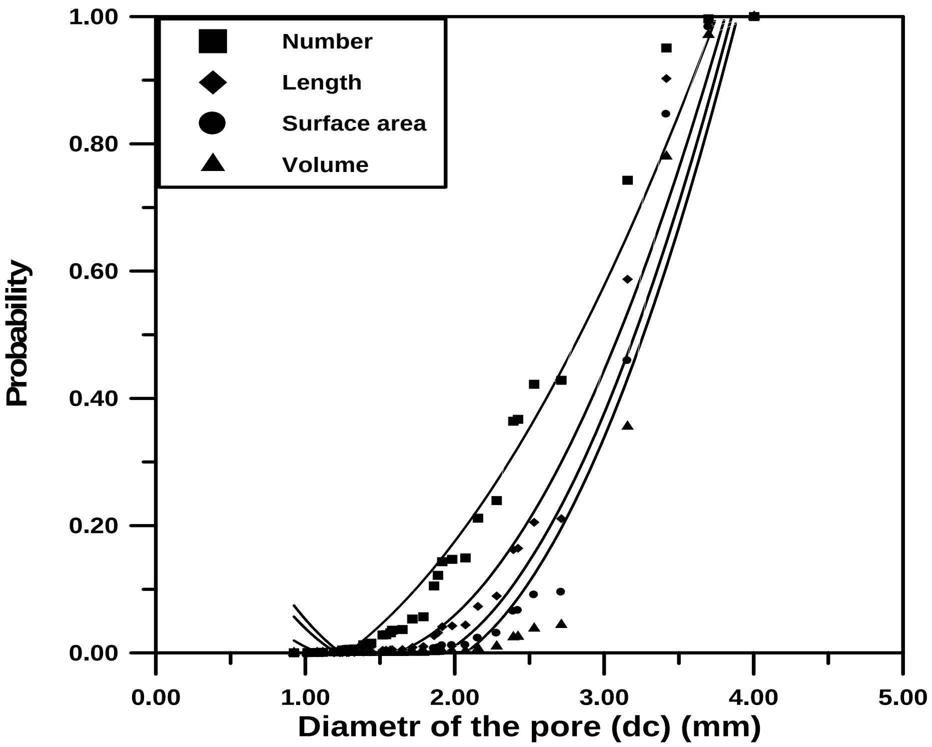

Figure 4.9 Pore Size Distribution Due to Number, Length, Area and Volume for: $N_1 = 0.035, N_2 = 0.045, N_3 = 0.09, N_4 = 0.68, N_5 = 0.15$

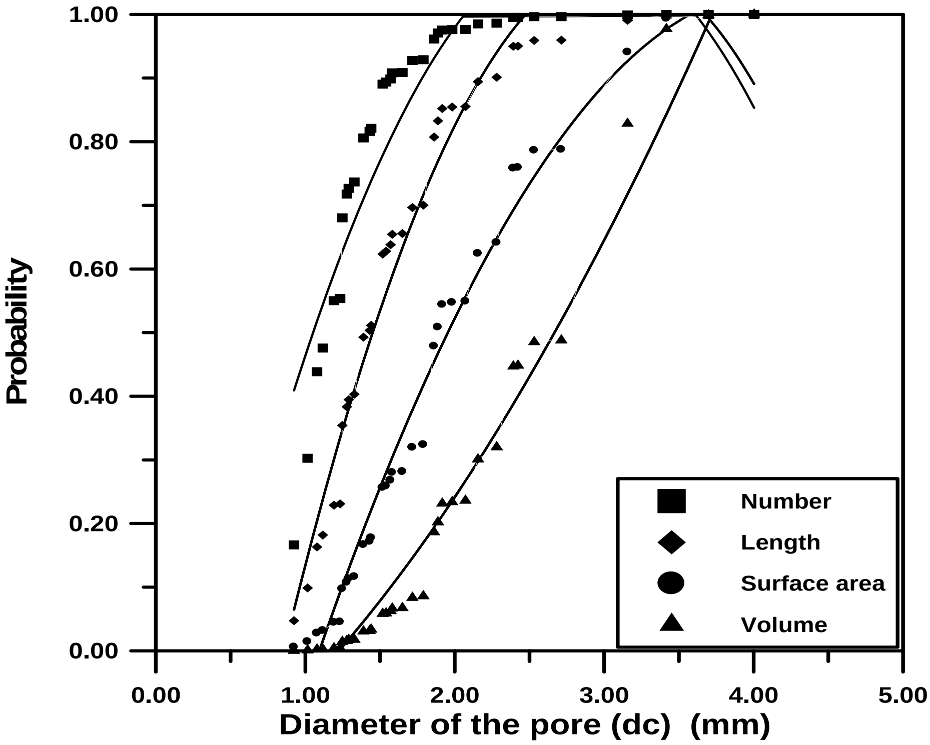

Figure 4.10 Pore Size Distribution Due to Number, Length, Area and Volume for: $\mathbf{N_1 = 0.55, N_2 = 0.15, N_3 = 0.15, N_4 = 0.14, N_5 = 0.01}$

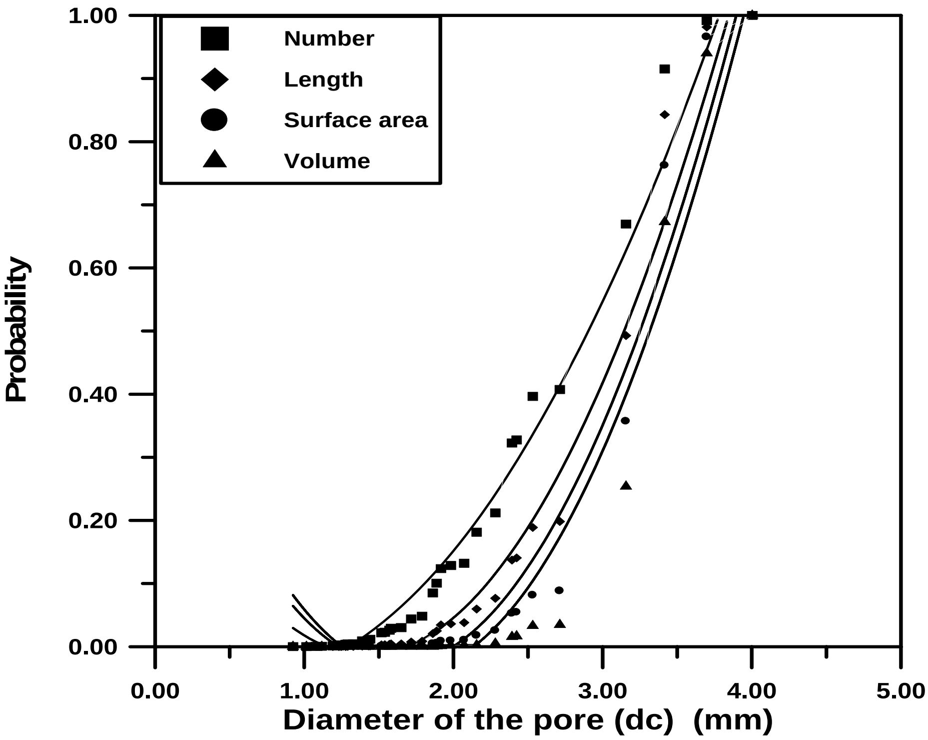

Figure 4.11 Pore Size Distribution Due to Number, Length, Area and Volume for: $\mathbf{N_1 = 0.03, N_2 = 0.04, N_3 = 0.09, N_4 = 0.64, N_5 = 0.2}$

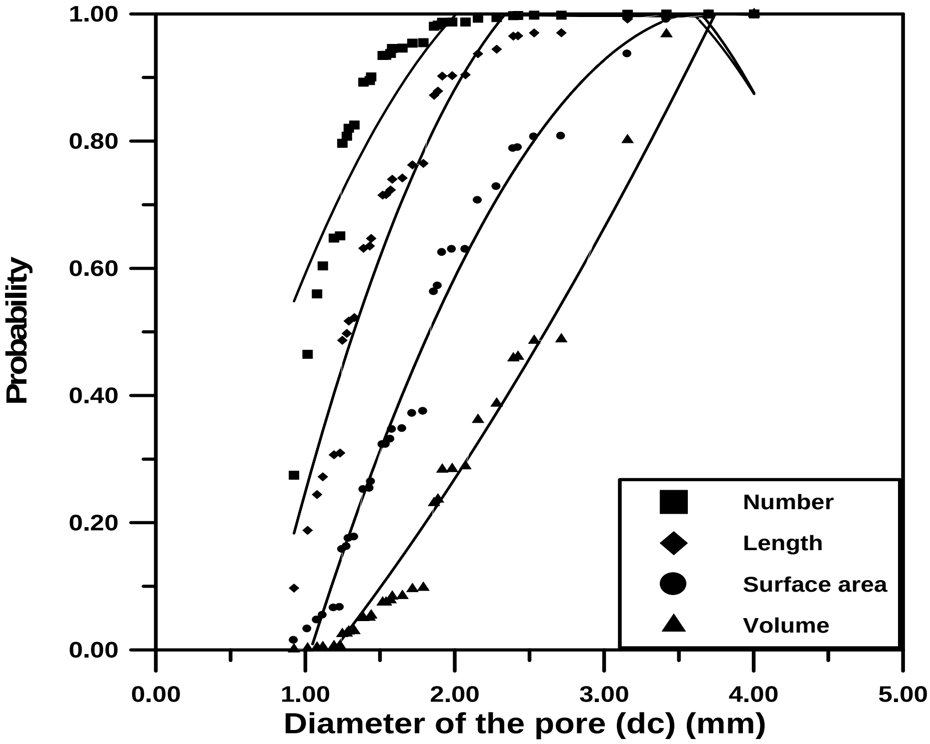

Figure 4.12 Pore Size Distribution Due to Number, Length, Area and Volume for: $\mathbf{N_1 = 0.65, N_2 = 0.15, N_3 = 0.075, N_4 = 0.115, N_5 = 0.01}$

4.2 Relationships Between Mean Pore Diameter and Percent Output of Impurities

The constant parameters in this work are the diameters of small, medium, and large sphere that any packed bed made from five sizes of spheres, these diameters are 6, 8, 10, 20 and 26 mm respectively.

Mean diameter of pores due to number is going to be related with the three types of impurities that will be passed from the packed bed and these types of impurities are:

1. Spheres of 1.2-2 mm
2. Spheres of 2-2.36 mm
3. Spheres of 2.36-3.15 mm

The above mixtures of spheres (impurities) are the same mixtures that are used in experimental work. It is necessary to find out that these mixtures are used for the experiments of the length, area, and volume distributions. So they are constant even if the type of distribution is changed, and the percent output of them is variable if the percents number, length, area, or volumes for the bed are changed.

The curves in figures 4.13 to 4.15 show proportionality between the mean pore diameters due to number and the percent output. It is clear from the figures, they are proportional to each other,(i.e. when the number of large spheres in any packed is increased ,so the weight of fine spheres (impurities)that leave the packed bed will be increased).This is the principle of increasing the mean pore size for the bed. The principle of reducing the mean pore diameter is done by, increasing the number of small or medium spheres in the packed bed.

For the mean pore diameter due to length ,the relations are made by relating this mean pore diameter with the same values of percent output of impurities that are obtained from experimental part. The difference between the case of length percent and number percent is in the shape of the curve .As shown in the figures 4.16 to 4.18, the results of the mean pore diameters(due to length ($dc_m l$) that are related with percent output) are acceptable compared with rest type of distribution. The same relations were made for mean pore diameter due to area ($dc_m a$) and volume ($dc_m v$).Figures 4.19 to 4.24 show the curves ,which relate the mean pore diameter due to area and volume with weight percent output for each type of impurities that are used in the experiment in this work. The value of mean pore diameter are taken from appendix[B] from tables B.14 to B.24.

Note that all the below figures are for diameters:-

d1=6,d2=8,d3=10,d4=20,d5=26 mm.

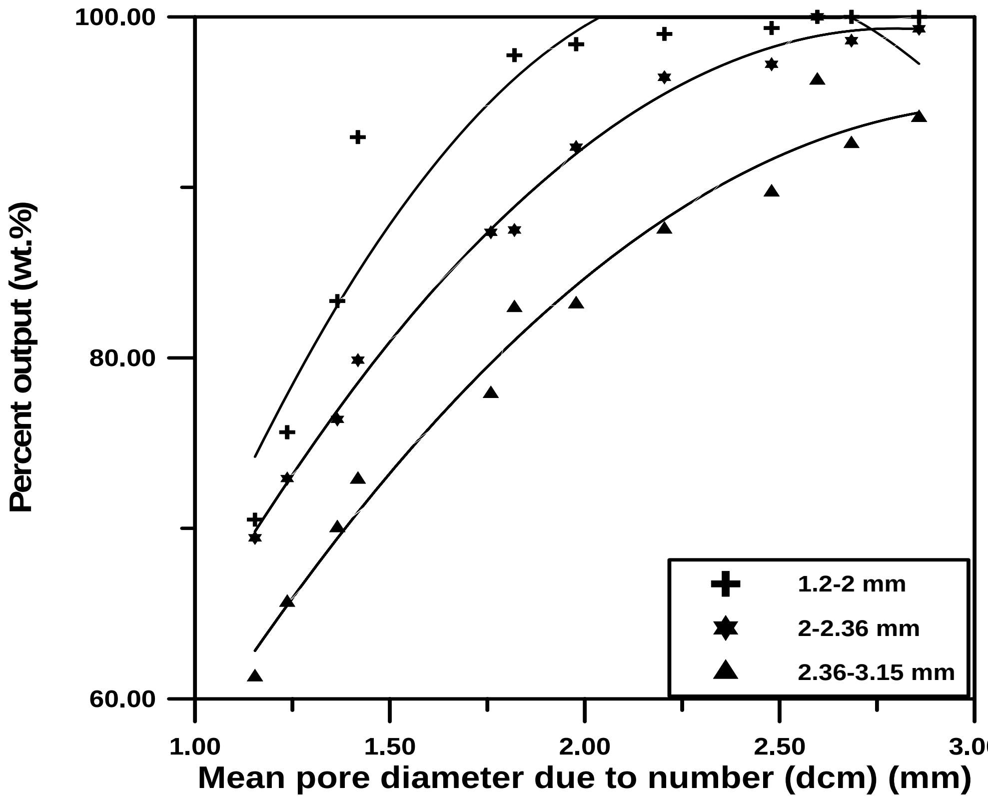

Figure 4.13 Mean Pore Diameter Due to Number Vs. Percent Output of Impurities for Two Layers.

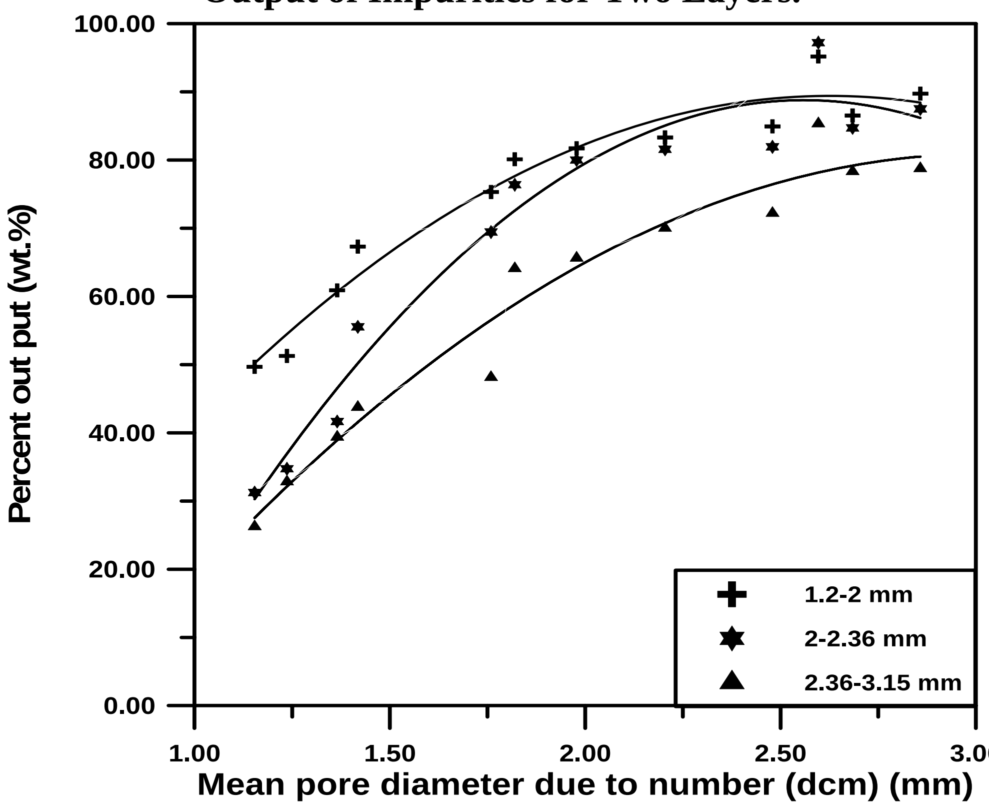

Figure 4.14 Mean Pore Diameter Due to Number Vs. Percent Output of Impurities for Three Layers.

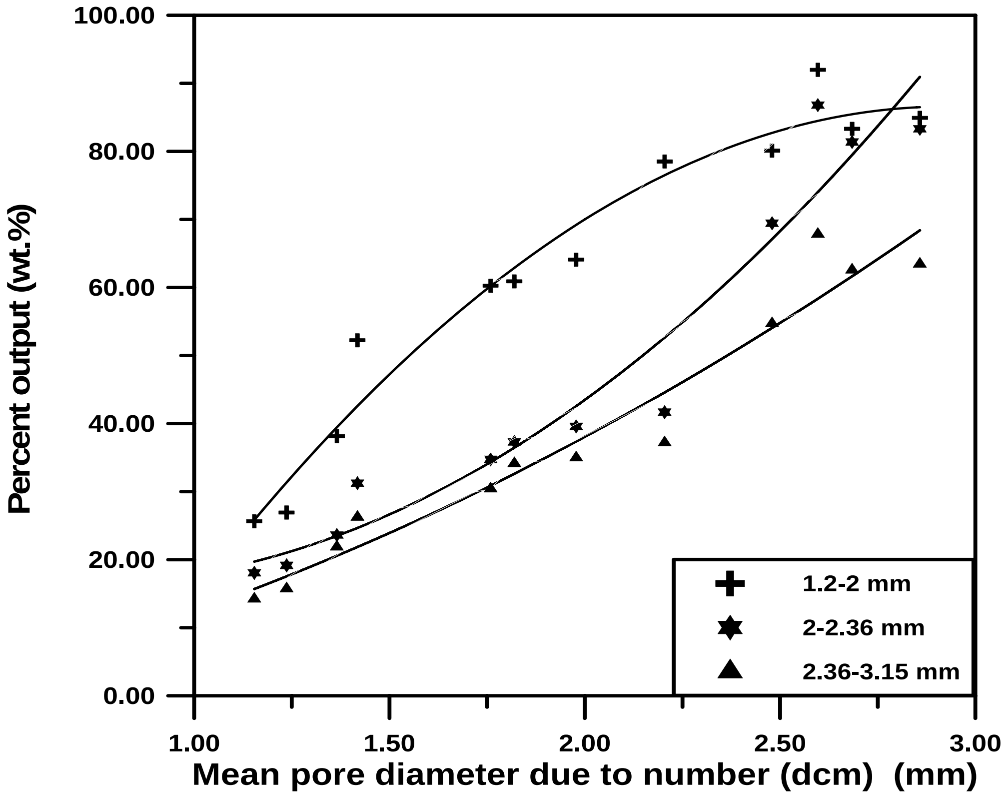

Figure 4.15 Mean Pore Diameter Due to Number Vs. Percent Output of Impurities for Four Layers

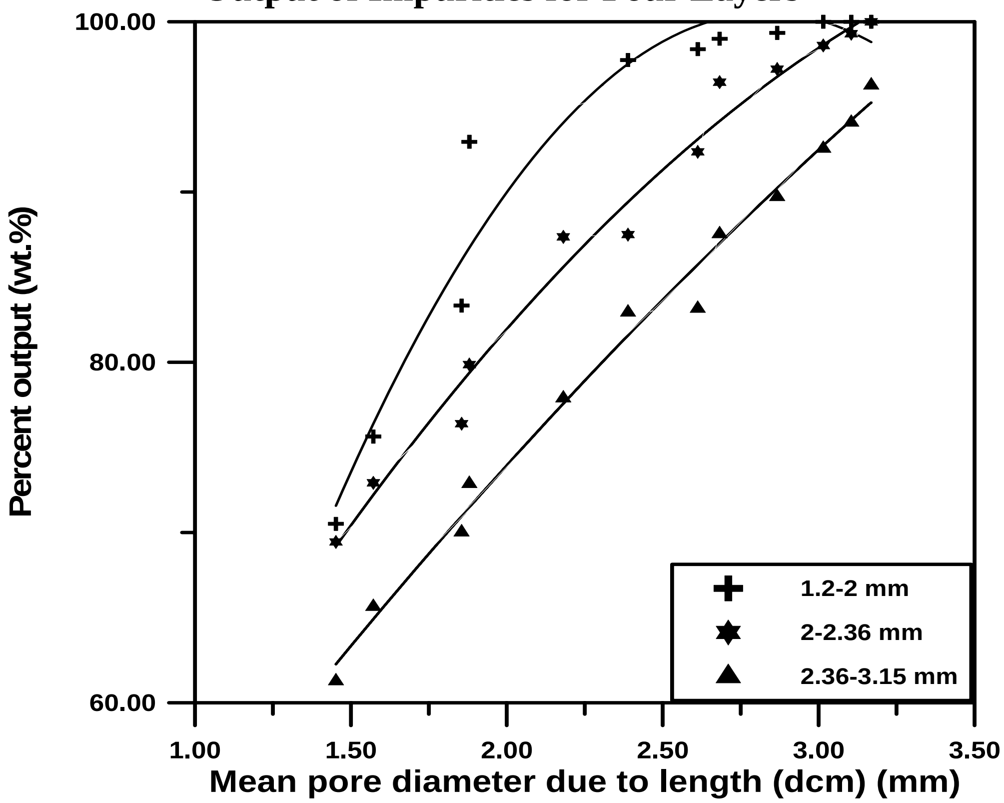

Figure 4.16 Mean Pore Diameter Due to Length Vs. Percent Output of Impurities for Two Layers

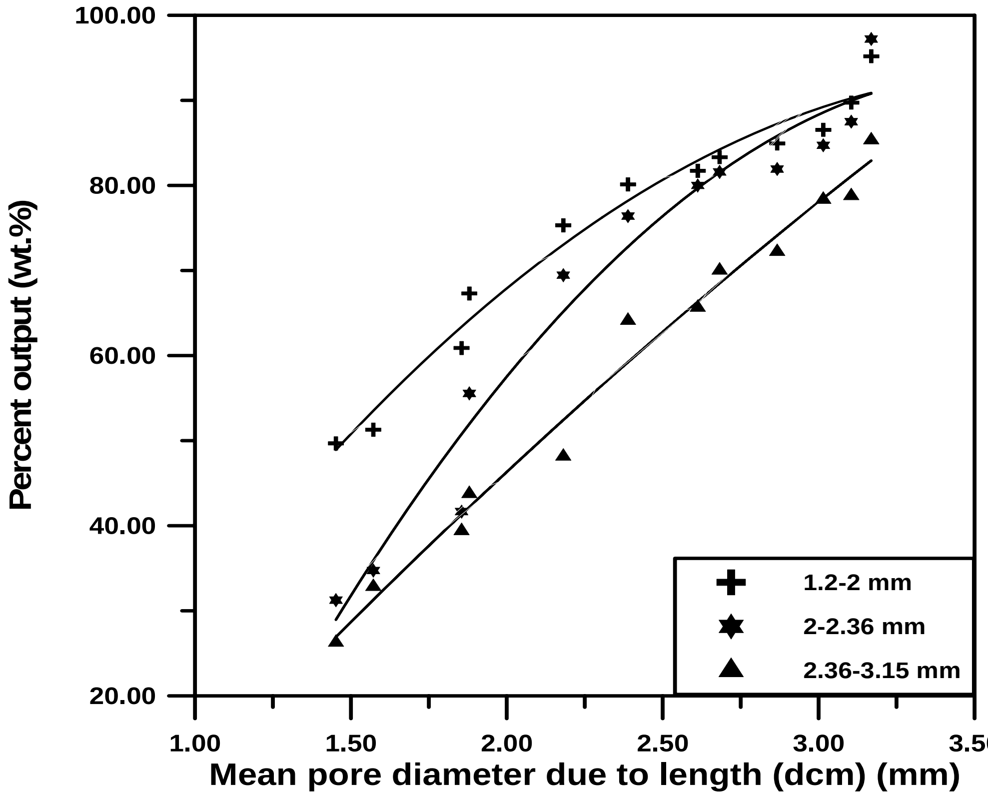

Figure 4.17 Mean Pore Diameter Due to Length Vs. Percent Out of Impurities for Three Layers

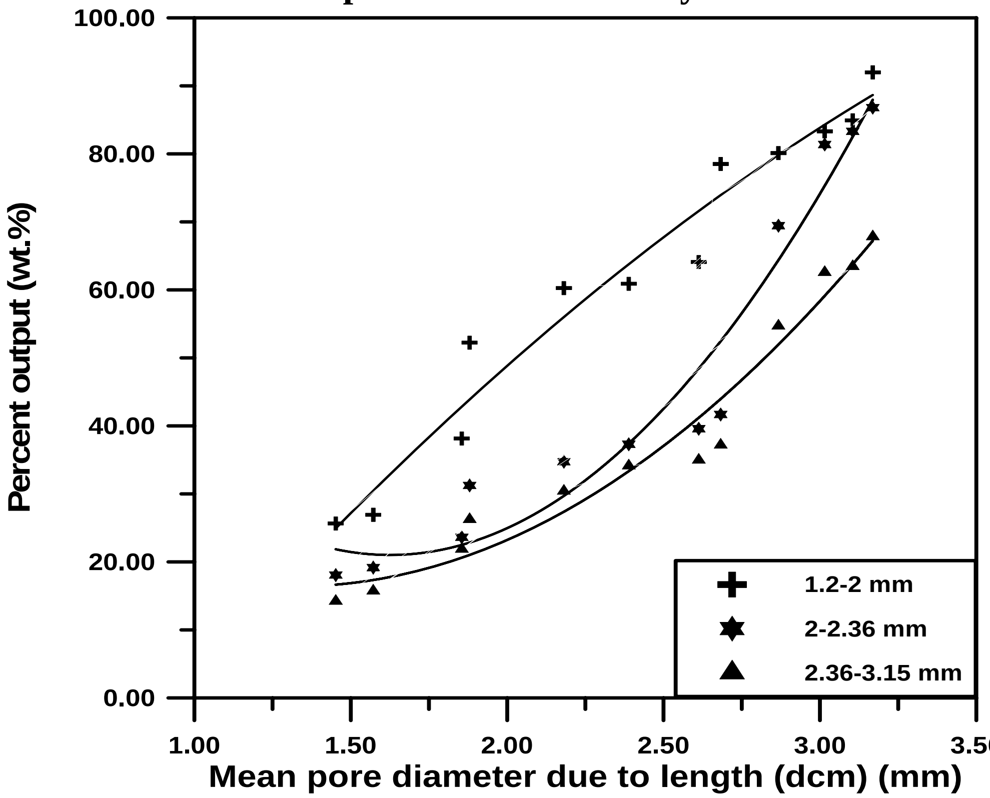

Figure 4.18 Mean Pore Diameter Due to Length Vs. Percent Out of Impurities for Four Layers

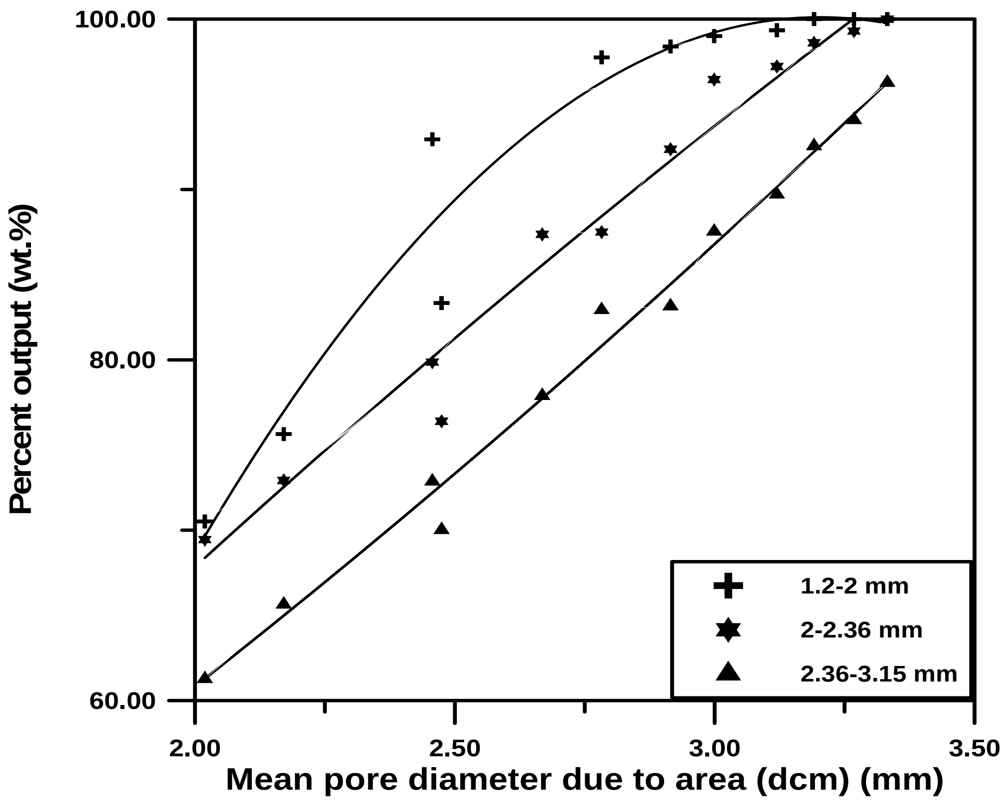

Figure 4.19 Mean Pore Diameter Due to Area Vs. Percent Output of Impurities for Two Layers.

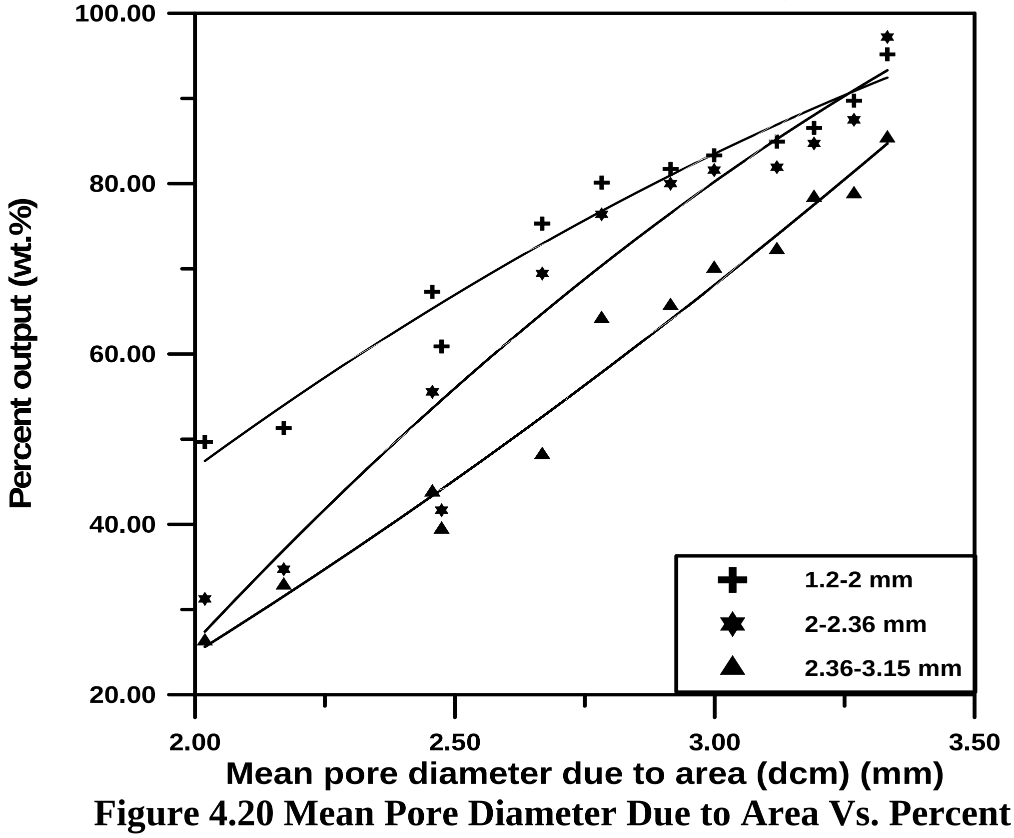

Figure 4.20 Mean Pore Diameter Due to Area Vs. Percent Output of Impurities for Three Layers.

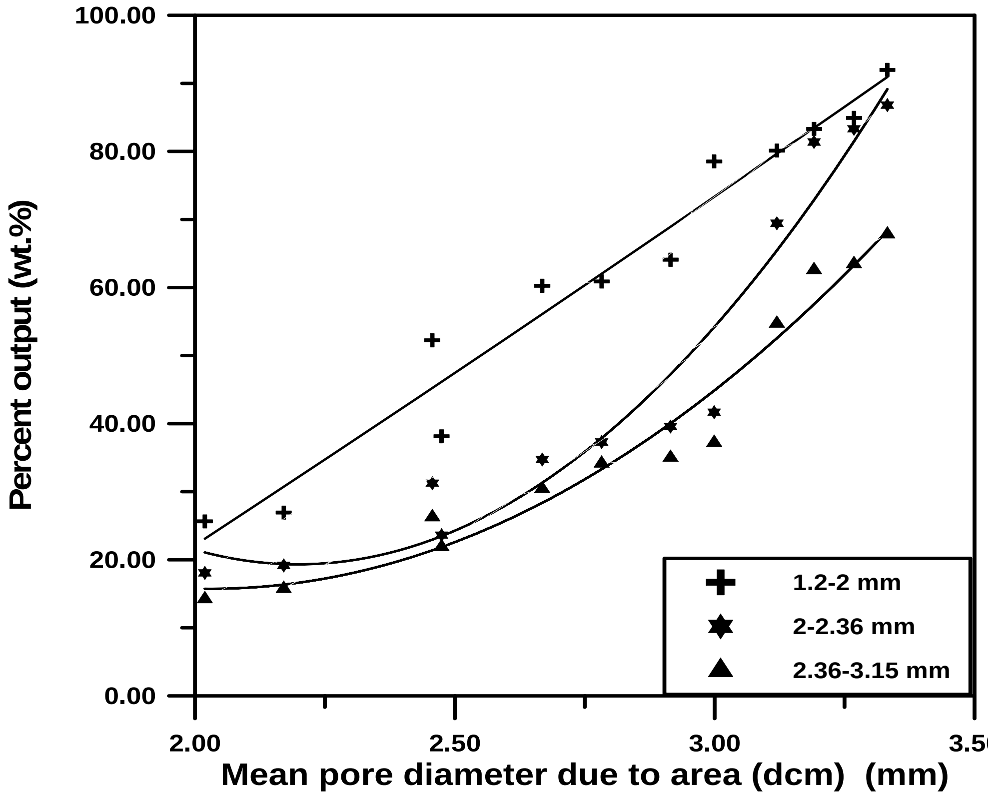

Figure 4.21 Mean Pore Diameter Due to Area Vs. Percent Output of Impurities for Four Layers.

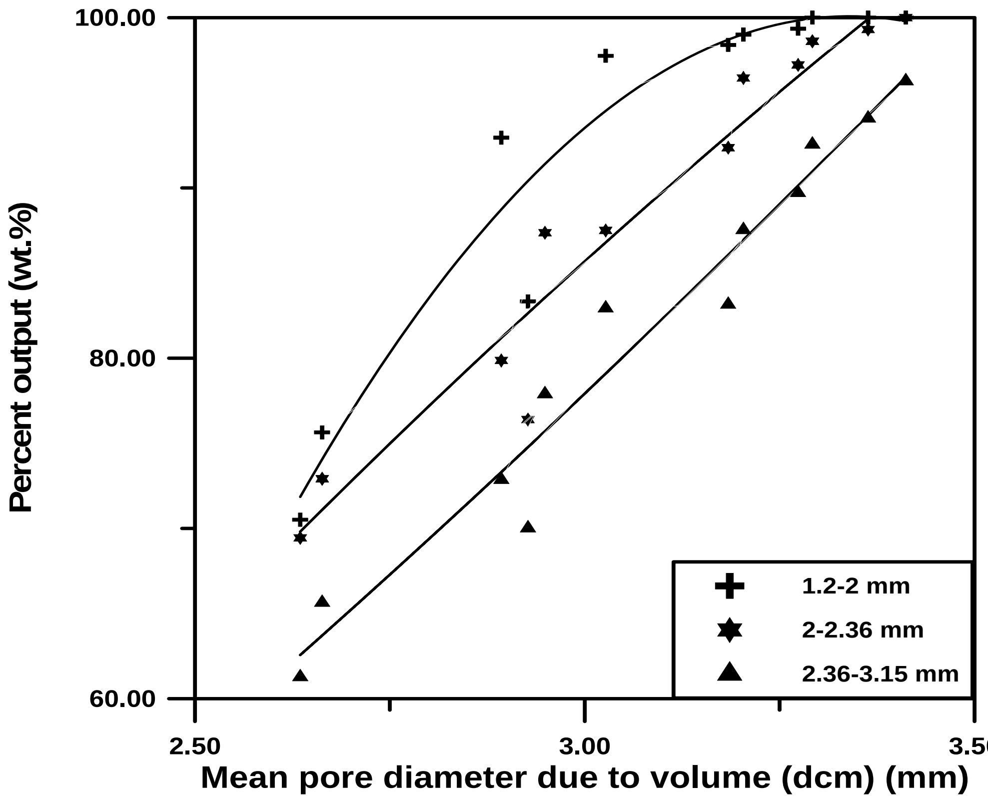

Figure 4.22 Mean Pore Diameter Due to Volume Vs. Percent Output of Impurities for Two Layers

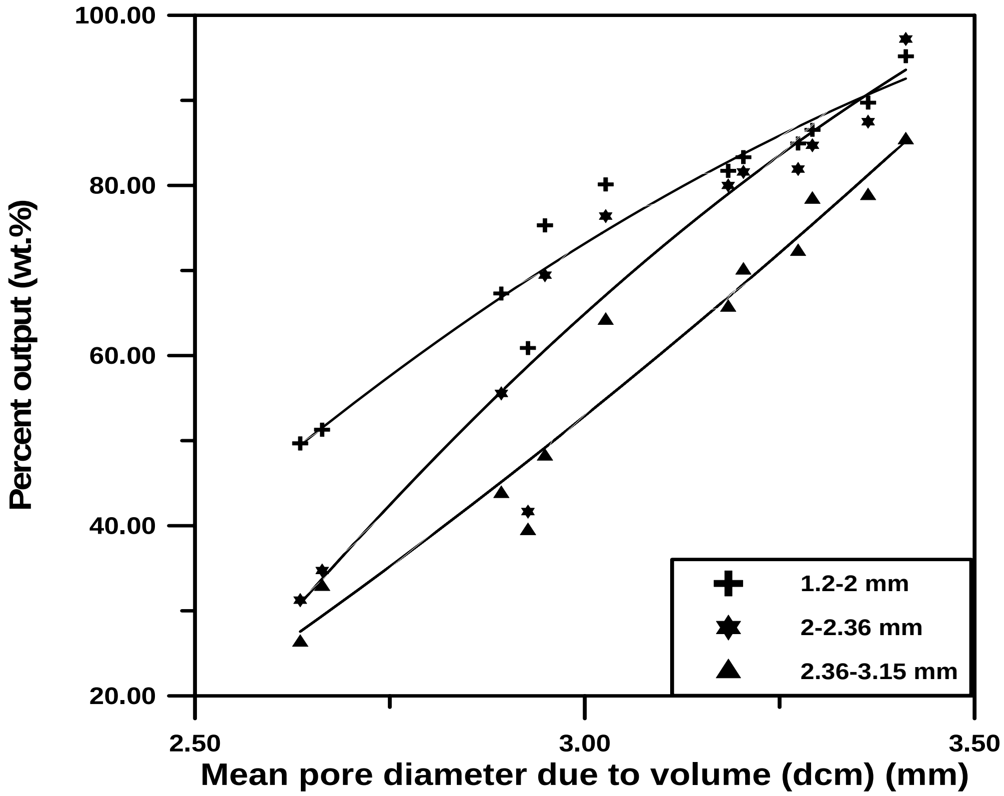

Figure 4.23 Mean Pore Diameter Due to Volume Vs. Percent Output of Impurities for Three Layers

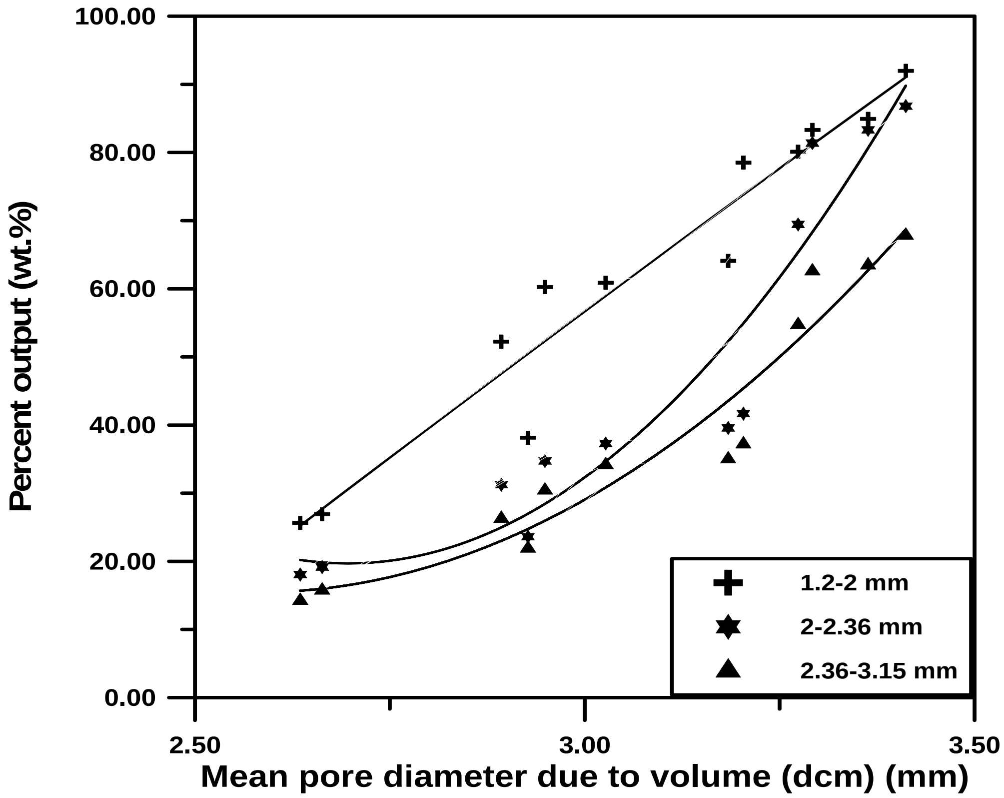

Figure 4.24 Mean Pore Diameter Due to Volume Vs. Percent Output of Impurities for Four Layers

4.3 Relationships Between Number of Layers and Percent Output of Impurities.

From the previous, it is known that the same kinds of sizes of impurities were used in the experiments in case of two, three and four layers.

The figures 4.25 to 4.36 show the proportionality between the number of layer and the percent output of impurities. It is obvious from the three curves of 1.2-2, 2-2.36 and 2.36-3.15 mm respectively, that when this kind of impurities are passed from the packed bed in case of two layers ,a large weight of output of impurities that leave the packed bed appeared ,and this weight decreased in the case of three layers and a noticeable decrease was seen in the case of the four layers ,hence it is obvious from the figures that when increasing the number of layers a decrease in the weight of output of impurities (leaving the packed bed)occurs, so the percent output of impurities will be decreased.

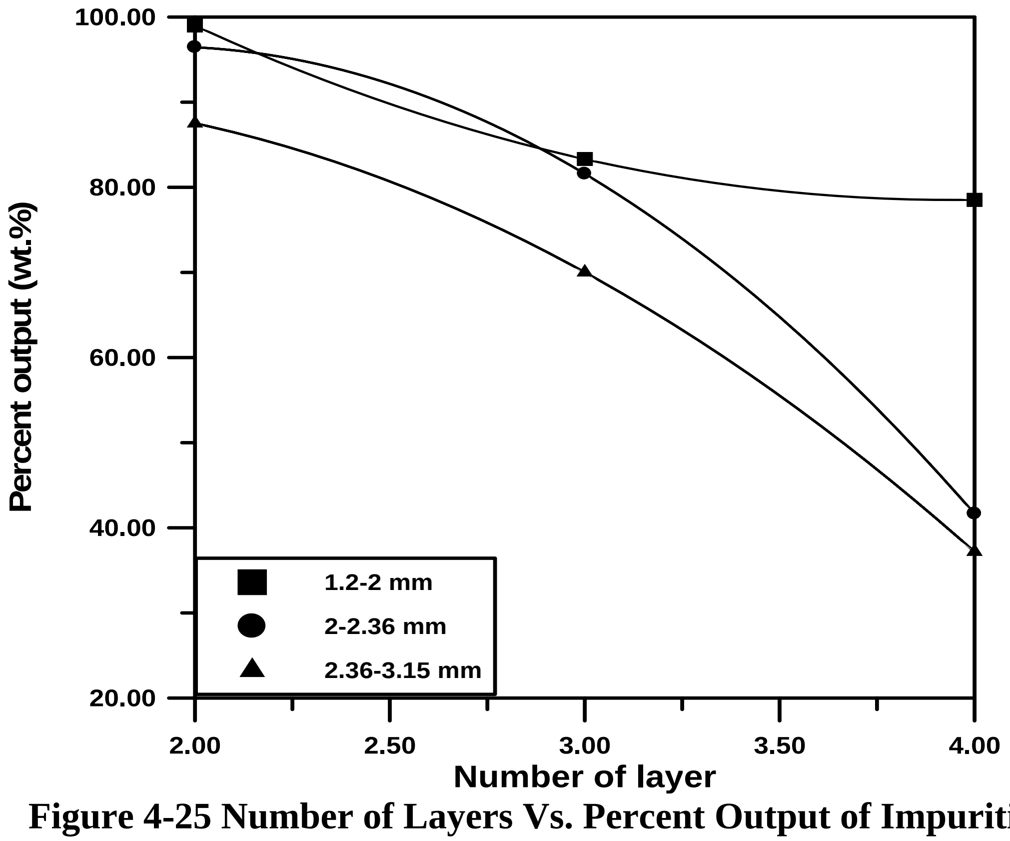

Figure 4-25 Number of Layers Vs. Percent Output of Impurities For: $N_1 = 0.1, N_2 = 0.1, N_3 = 0.2, N_4 = 0.54, N_5 = 0.06$

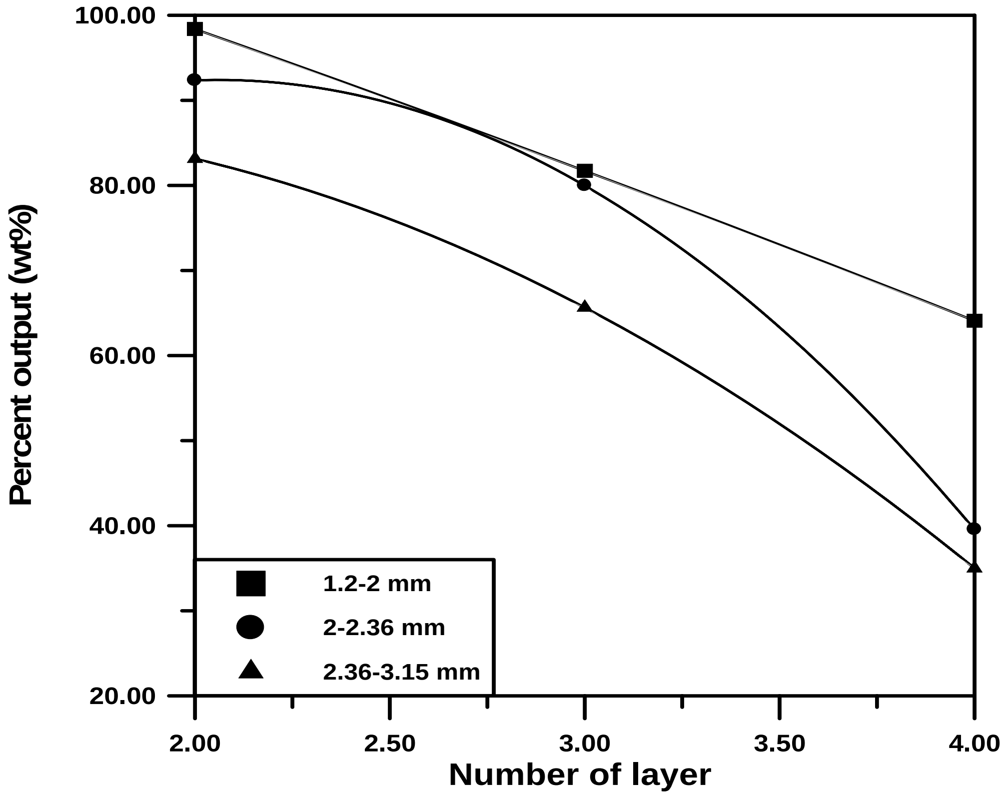

Figure 4.26 Number of Layers Vs. Percent Output of Impurities
For: $N_1 = 0.15, N_2 = 0.15, N_3 = 0.2, N_4 = 0.44, N_5 = 0.06$

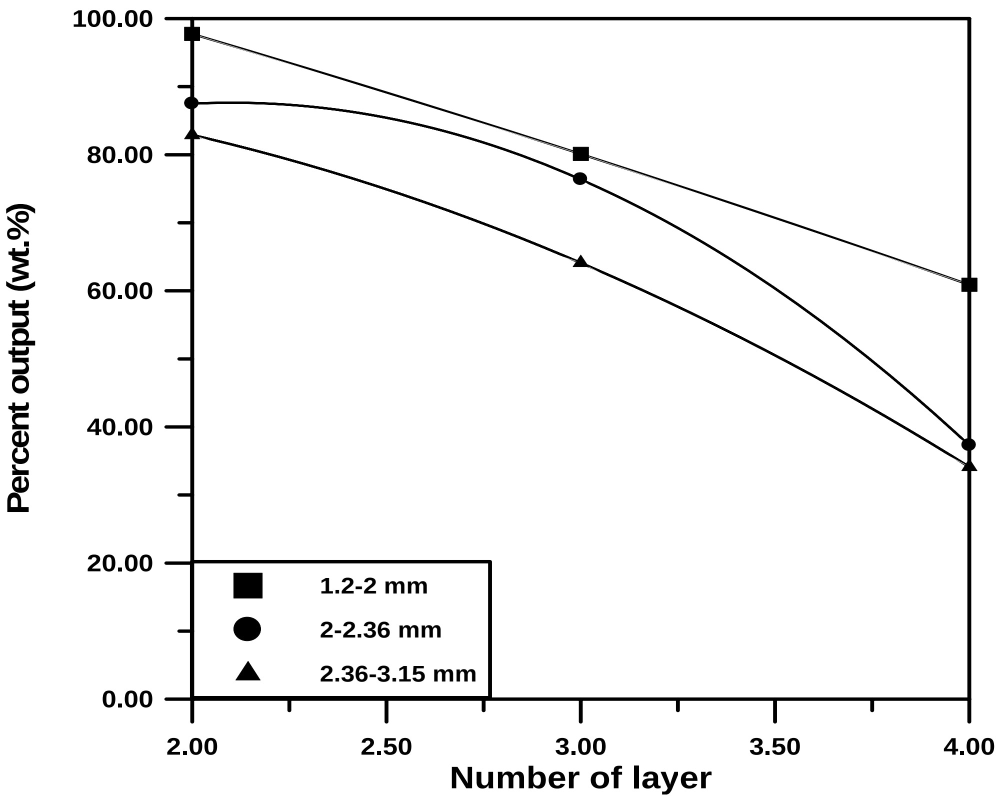

Figure 4.27 Number of Layers Vs. Percent Output of Impurities
For : $N_1 = 0.2, N_2 = 0.2, N_3 = 0.15, N_4 = 0.43, N_5 = 0.02$

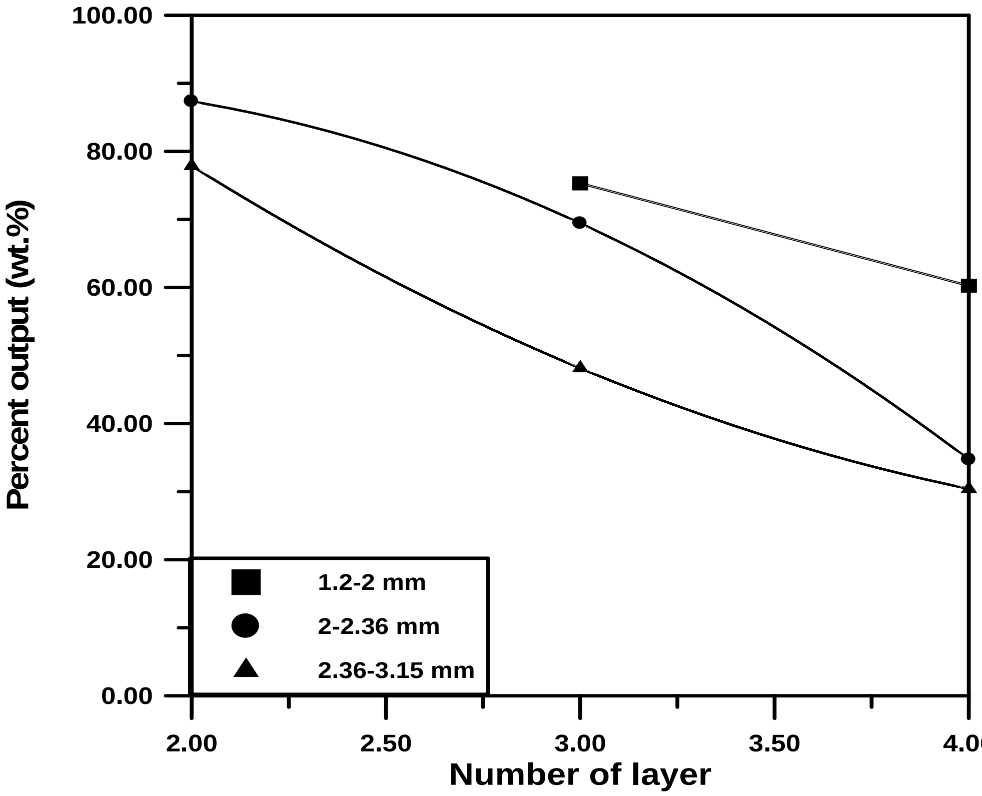

Figure 4.28 Number of Layers Vs. Percent Output of Impurities
For: $N_1 = 0.25, N_2 = 0.2, N_3 = 0.182, N_4 = 0.348, N_5 = 0.02$

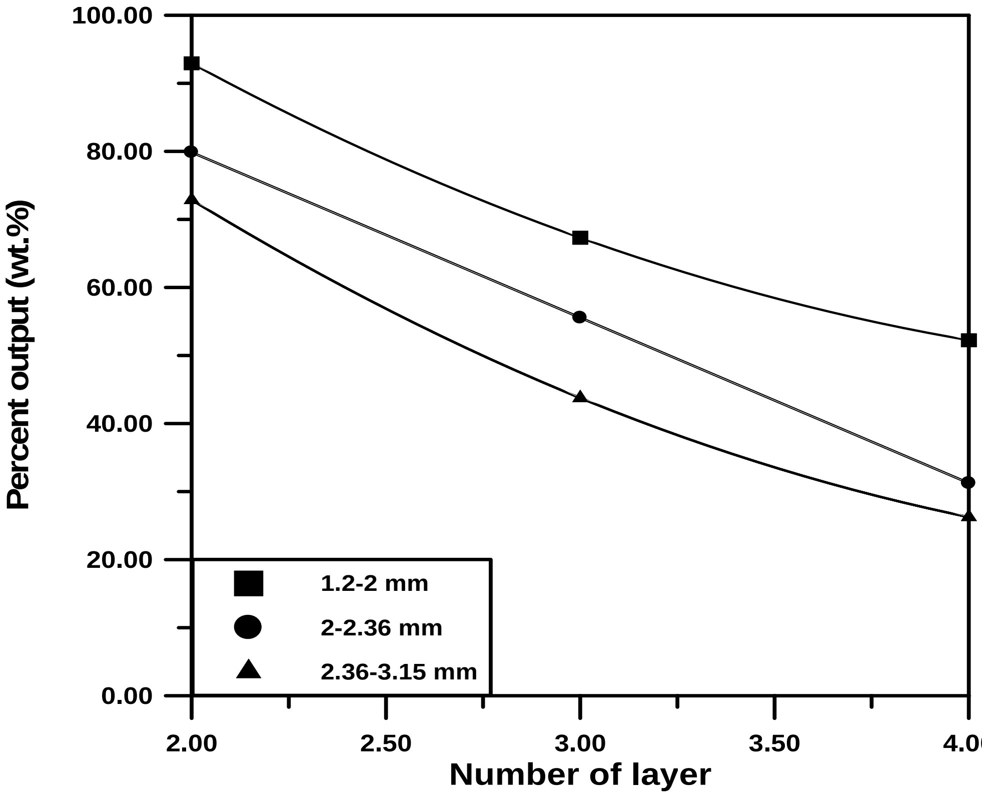

Figure 4.29 Number of Layers Vs. Percent Output of Impurities
For: $N_1 = 0.4, N_2 = 0.2, N_3 = 0.15, N_4 = 0.23, N_5 = 0.02$

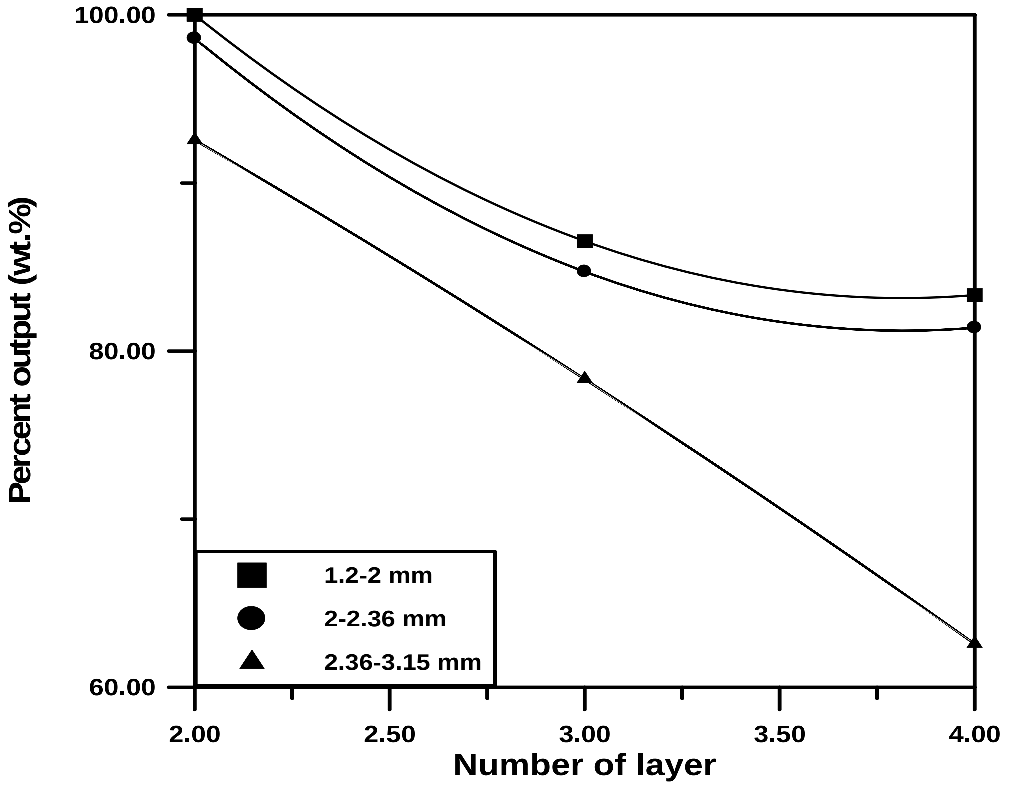

Figure 4.30 Number of Layers Vs. Percent Output of Impurities: For: $N_1 = 0.05, N_2 = 0.06, N_3 = 0.09, N_4 = 0.7, N_5 = 0.1$

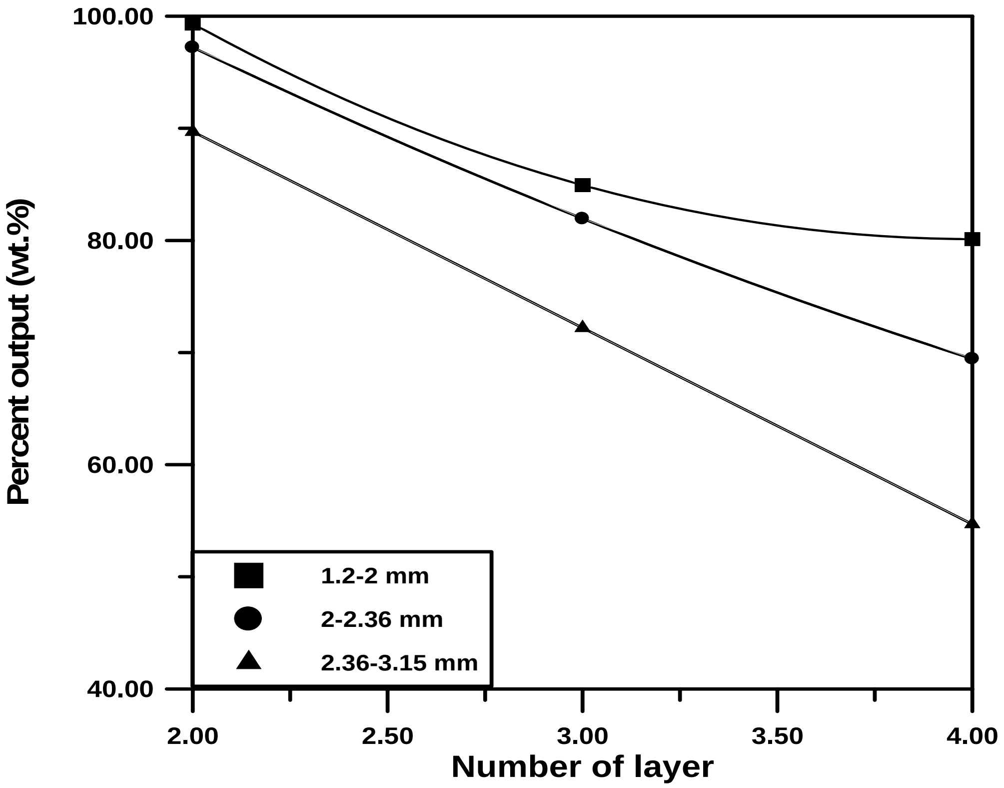

Figure4.31 Number of Layers Vs. Percent Output of Impurities For: $N_1 = 0.5, N_2 = 0.132, N_3 = 0.118, N_4 = 0.23, N_5 = 0.02$

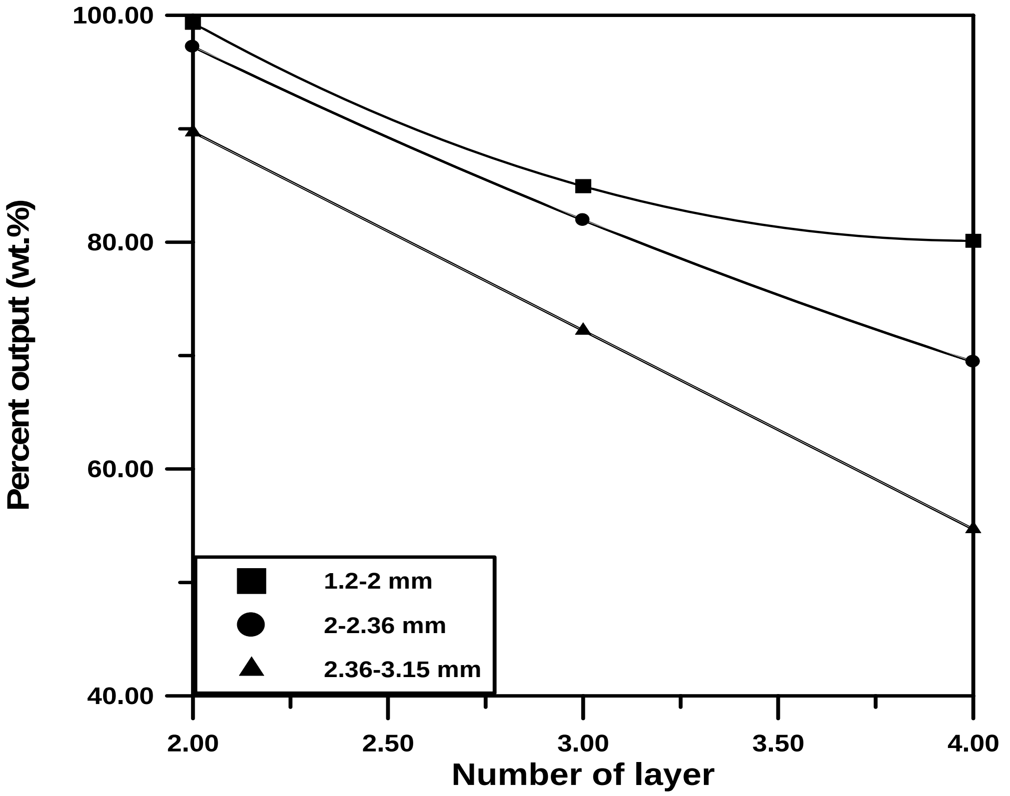

Figure4.32 Number of Layers Vs. Percent Output of Impurities
For: $N_1 = 0.07, N_2 = 0.09, N_3 = 0.14, N_4 = 0.61, N_5 = 0.09$

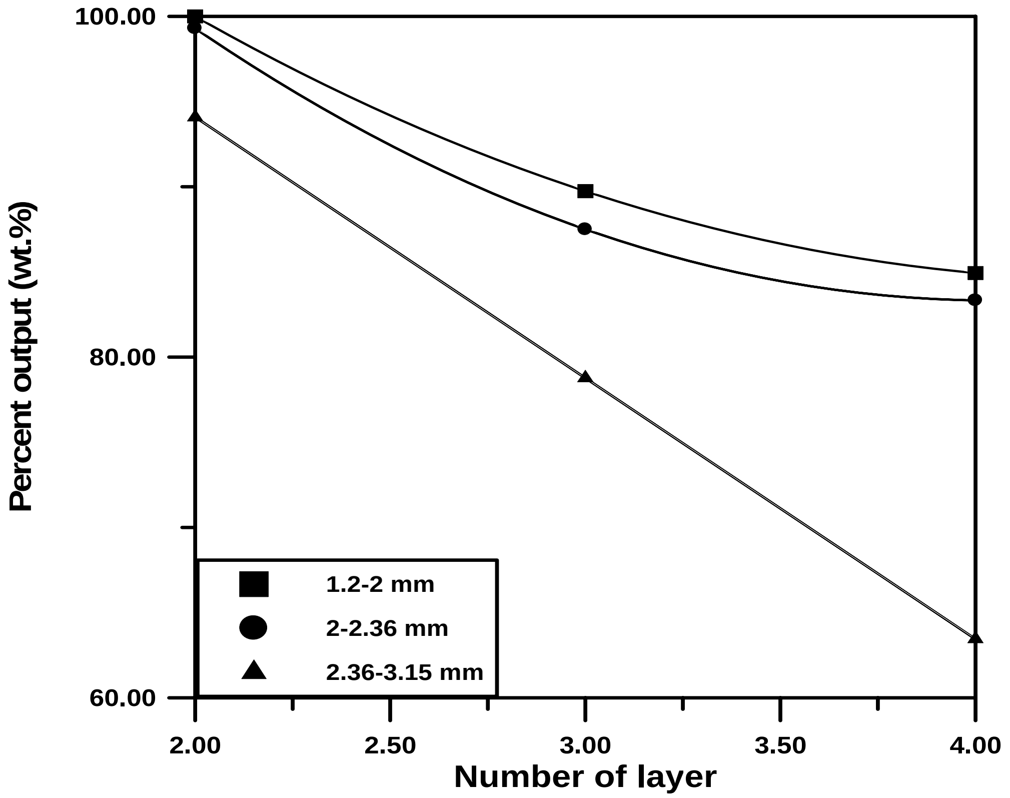

Figure4.33 Number of Layers Vs. Percent Output of Impurities
For: $N_1 = 0.035, N_2 = 0.045, N_3 = 0.09, N_4 = 0.68, N_5 = 0.15$

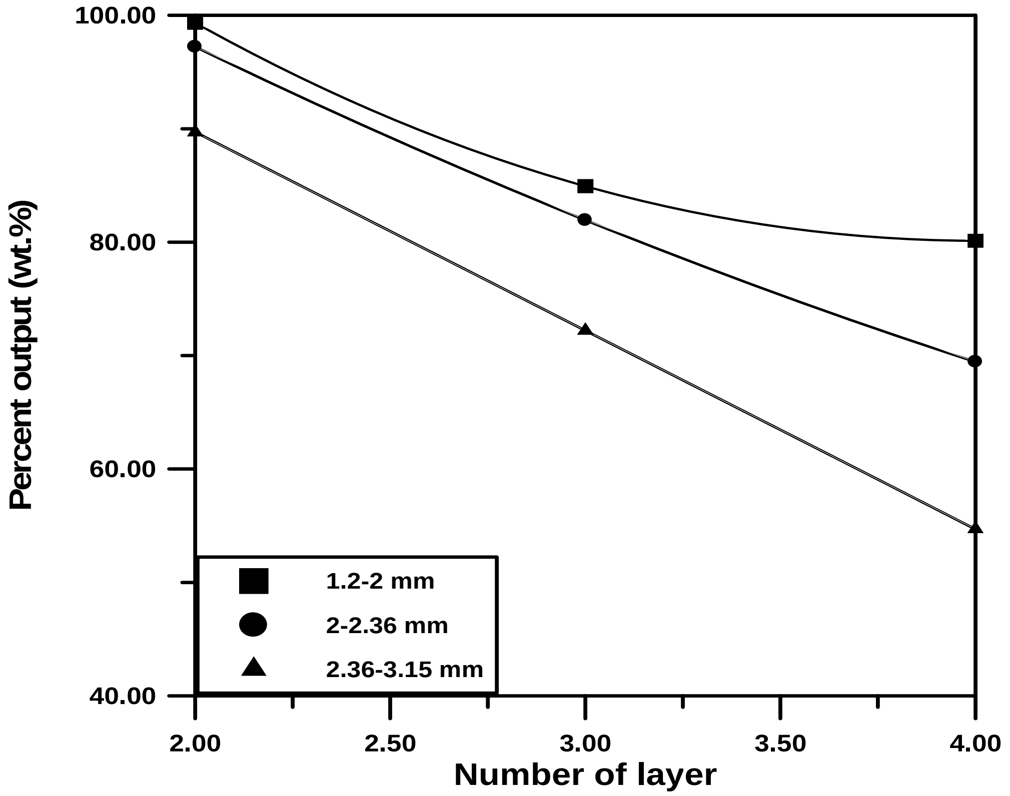

Figure 4.34 Number of Layers Vs. Percent Output of Impurities
For: $N_1 = 0.55, N_2 = 0.15, N_3 = 0.15, N_4 = 0.14, N_5 = 0.01$

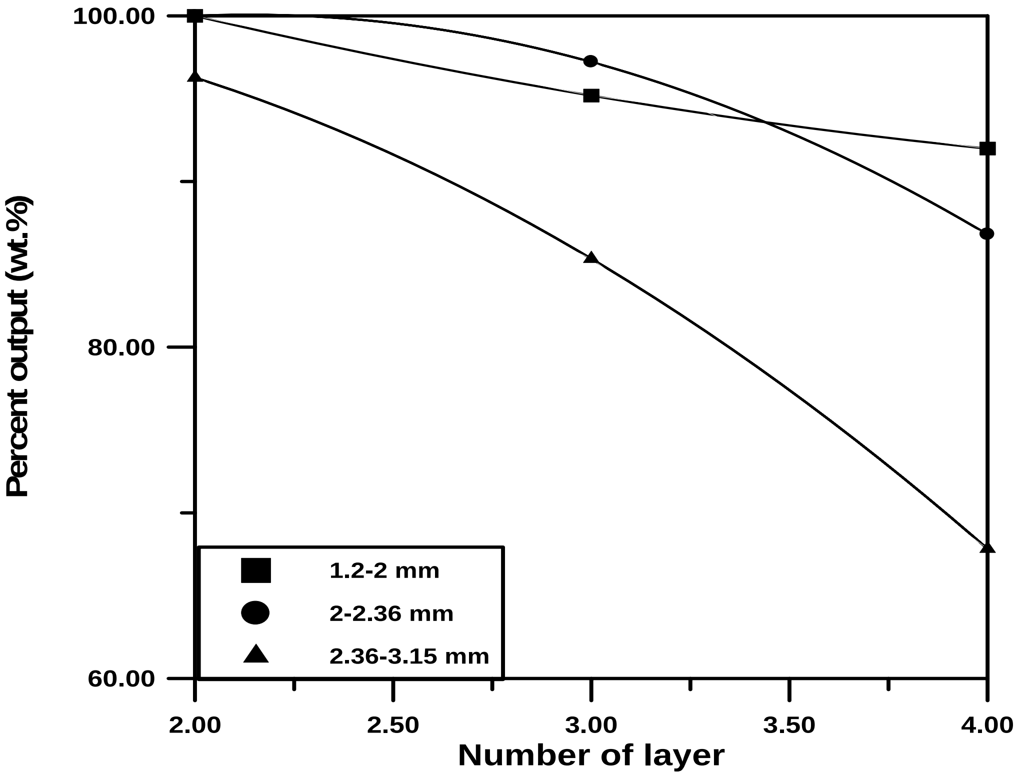

Figure 4.35 Number of Layers Vs. Percent Output of Impurities
For: $N_1 = 0.03, N_2 = 0.04, N_3 = 0.09, N_4 = 0.64, N_5 = 0.2$

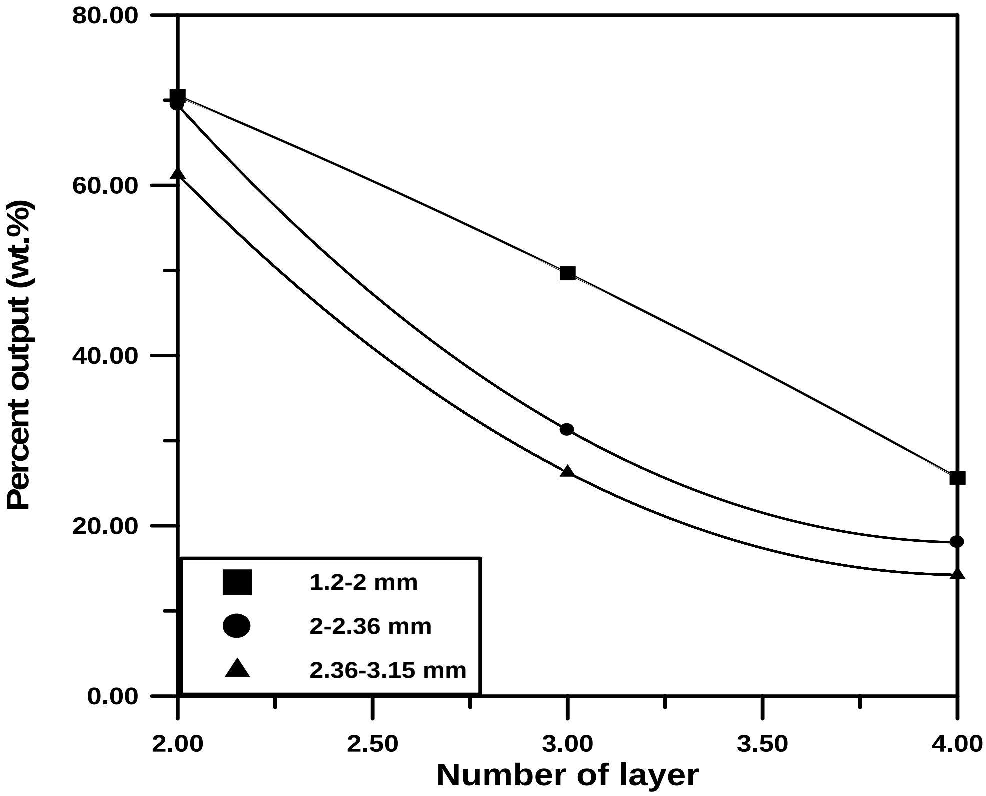

Figure 4.36 Number of Layers Vs. Percent Output of Impurities For: $N_1 = 0.65, N_2 = 0.15, N_3 = 0.075, N_4 = 0.115, N_5 = 0.01$

4.4 Relationships Between The Size of Impurities and Percent Output of Impurities.

In this section , the size of impurities will be related with the weight percent output of impurities for each packed bed made from five sizes of spheres.

The curves of this relation are shown Figure 4.37 to 4.48.These curves show the relation between the size of impurities and the percent output of impurities. It is obvious from the figures that when impurities of large size are passed in the packed bed lead to decrease in the weight of output of impurities (leaving the packed bed) has occurred, so this will lead to decrease in the weight of out put of impurities and this decrease is noticeable in the case of 1.2-2,2-2.36 and 2.36-3.15 mm respectively. While the percent output of impurities will increase with the decrease in the size of impurities.

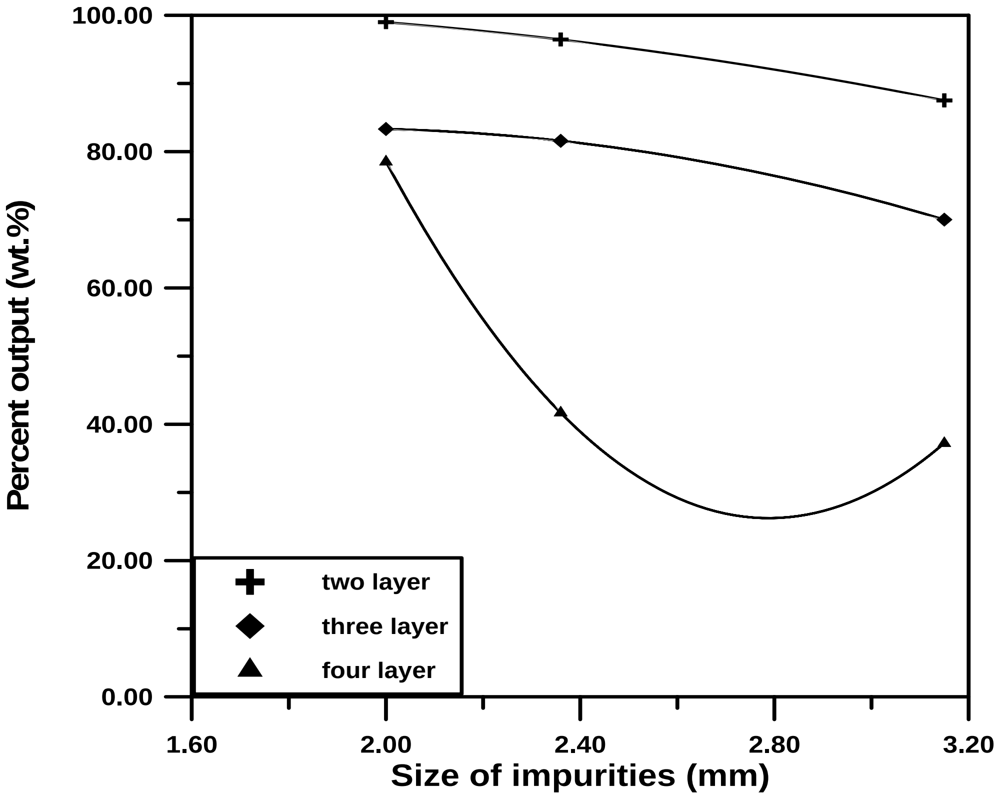

Figure 4.37 Size of Impurities Vs. Percent Output of Impurities
For: $N_1 = 0.1, N_2 = 0.1, N_3 = 0.2, N_4 = 0.54, N_5 = 0.06$

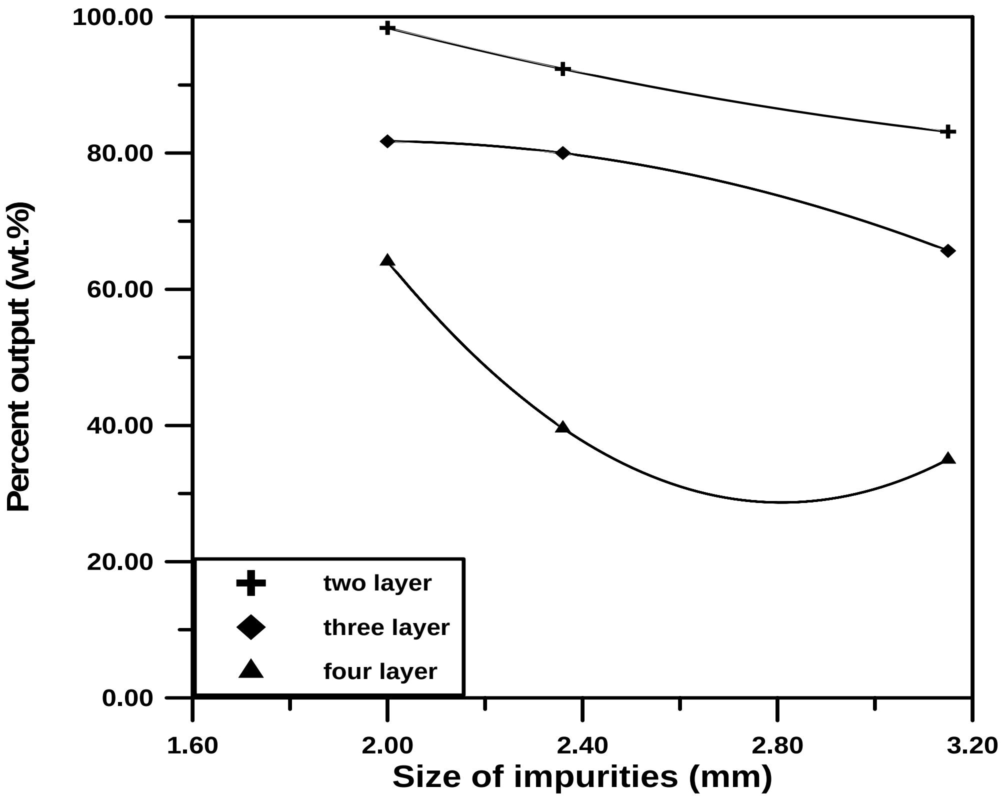

Figure 4.38 Size of Impurities Vs. Percent Output of Impurities
For: $N_1 = 0.15, N_2 = 0.15, N_3 = 0.2, N_4 = 0.44, N_5 = 0.06$

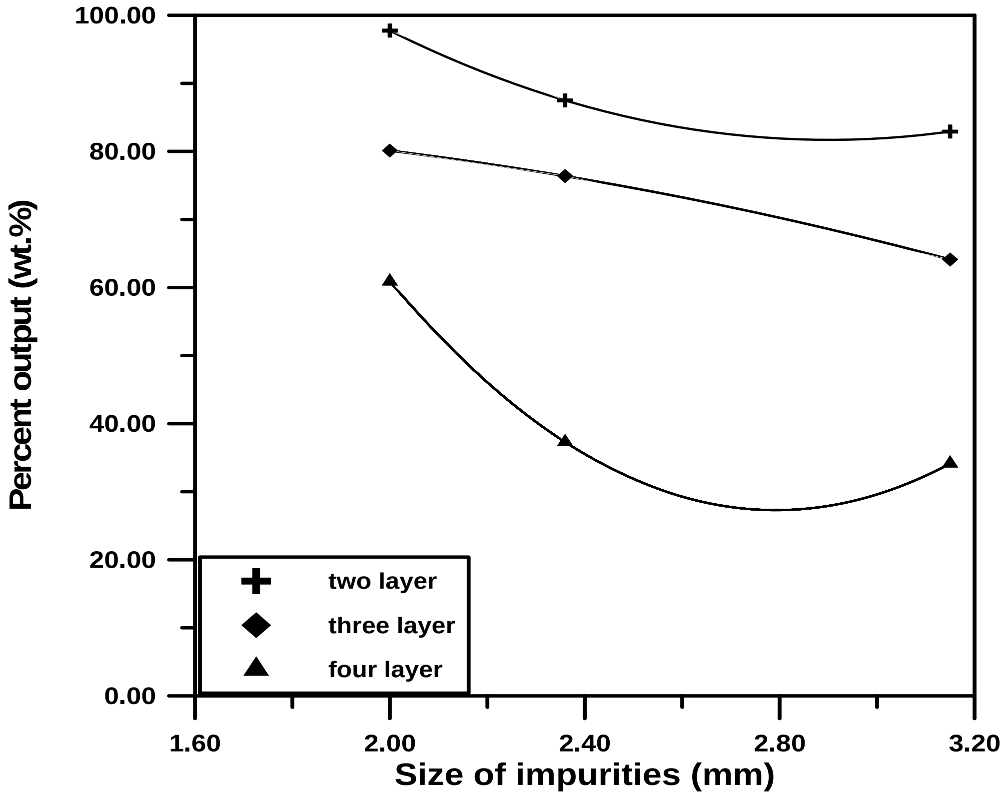

Figure 4.39 Size of Impurities Vs. Percent Output of Impurities
For: $N_1 = 0.2, N_2 = 0.2, N_3 = 0.15, N_4 = 0.43, N_5 = 0.02$

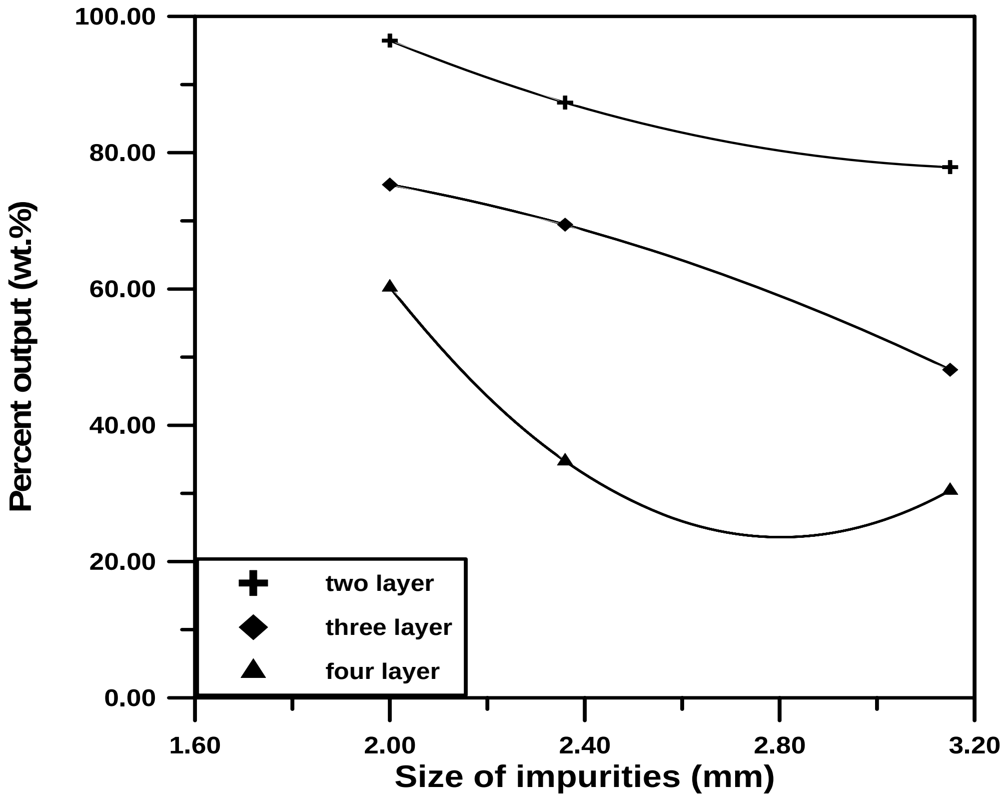

Figure 4.40 Size of Impurities Vs. Percent Output of Impurities
For: $N_1 = 0.25, N_2 = 0.2, N_3 = 0.182, N_4 = 0.348, N_5 = 0.02$

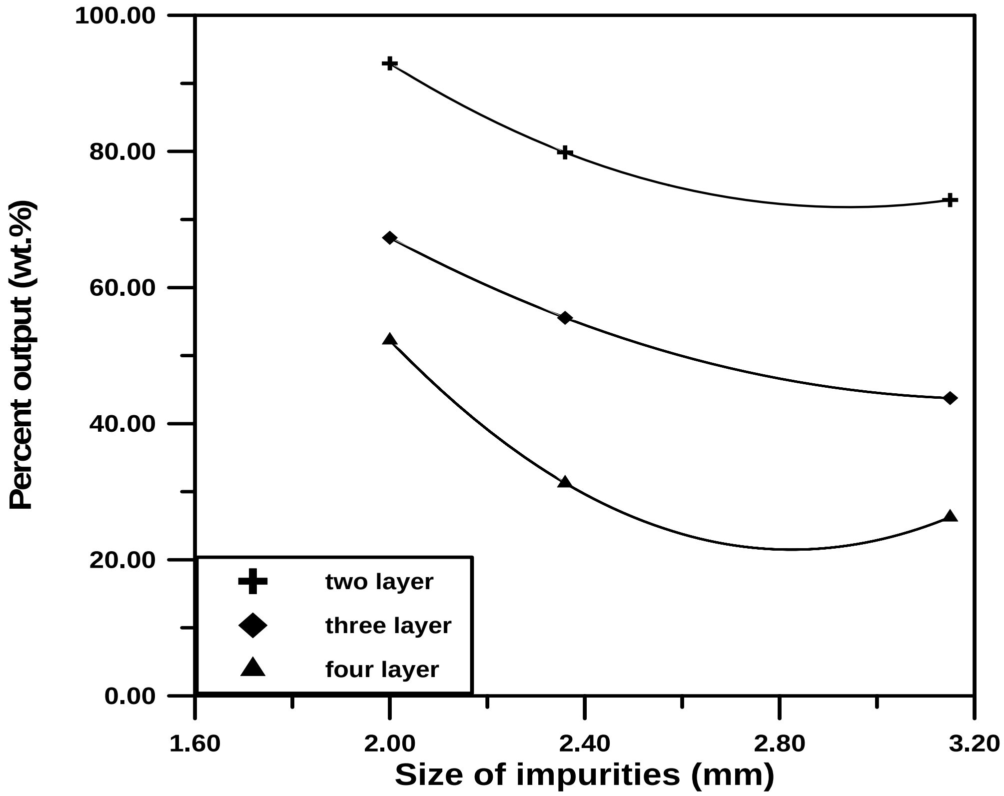

Figure 4.41 Size of Impurities Vs. Percent Output of Impurities For: $N_1 = 0.4, N_2 = 0.2, N_3 = 0.15, N_4 = 0.23, N_5 = 0.02$

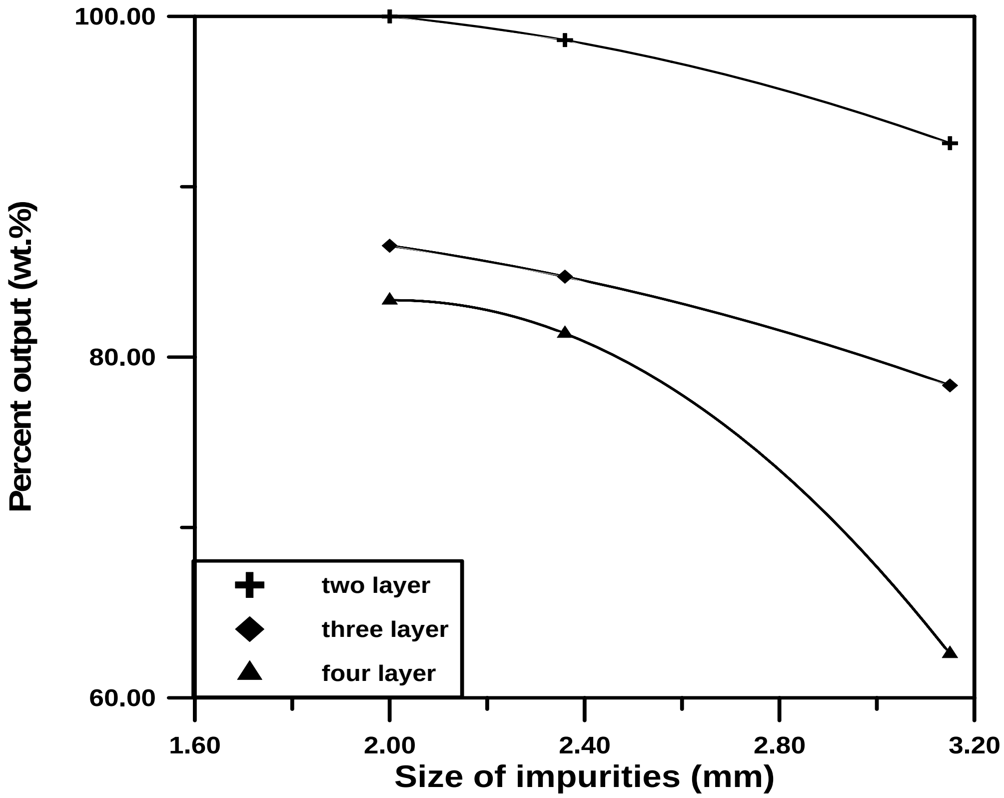

Figure 4.42 Size of Impurities Vs. Percent Output of Impurities For: $N_1 = 0.05, N_2 = 0.06, N_3 = 0.09, N_4 = 0.7, N_5 = 0.1$

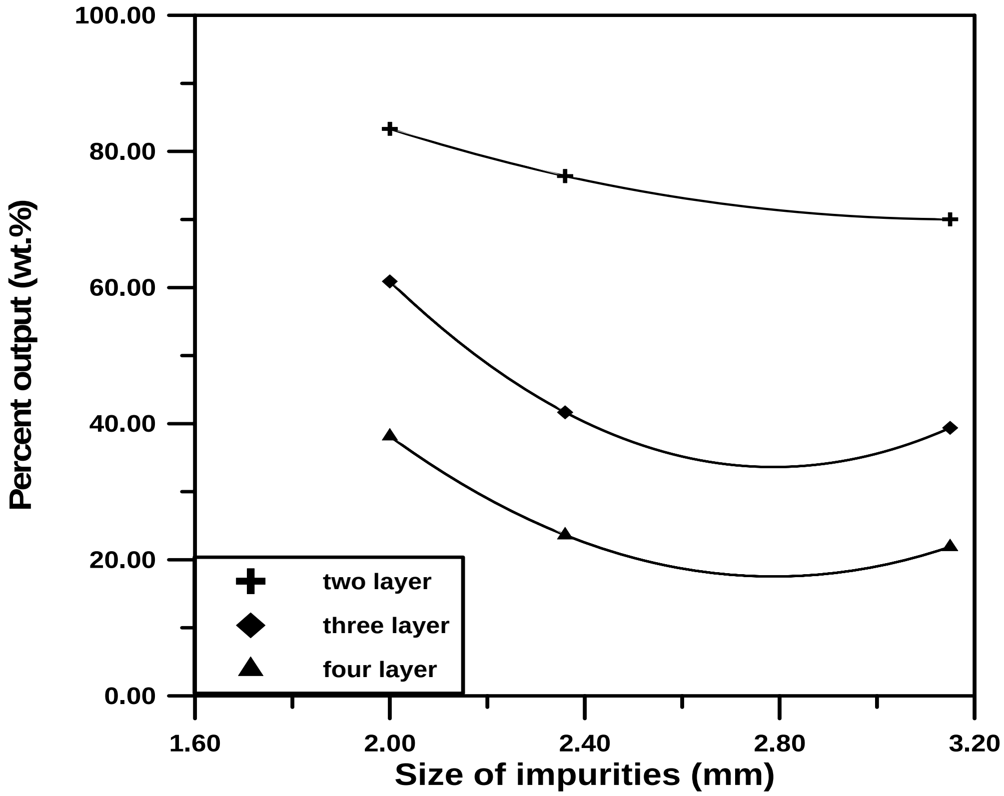

Figure 4.43 Size of Impurities Vs. Percent Output of Impurities
For: $N_1 = 0.5, N_2 = 0.132, N_3 = 0.118, N_4 = 0.23, N_5 = 0.02$

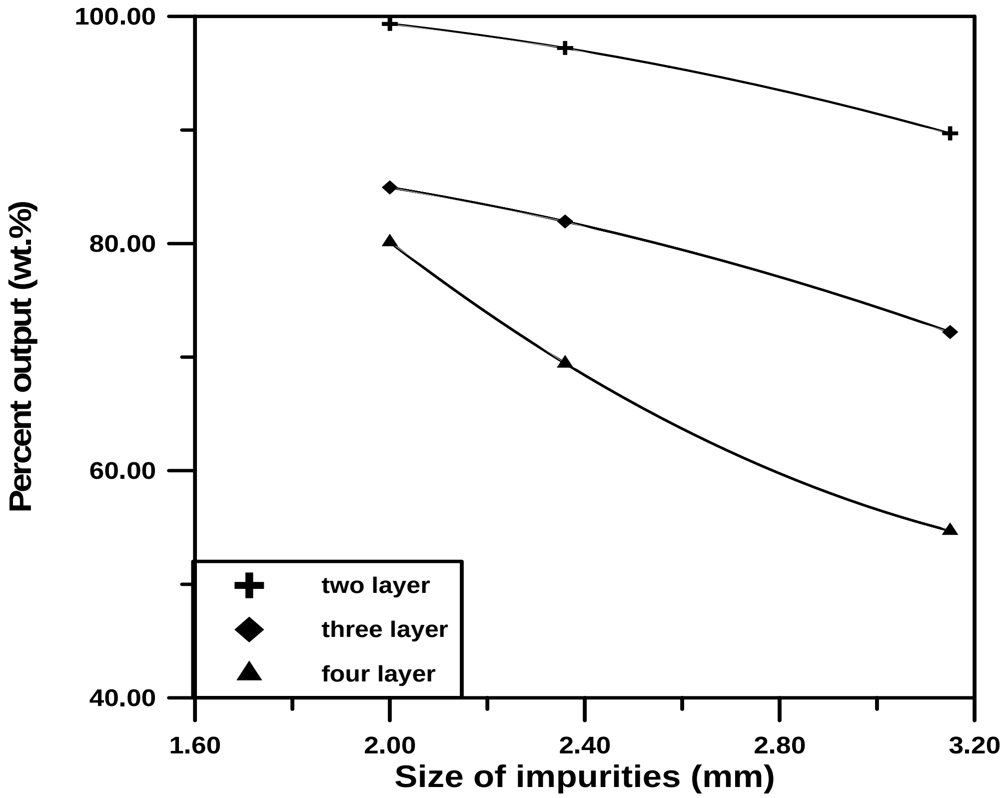

Figure 4.44 Size of Impurities Vs. Percent Output of Impurities
For: $N_1 = 0.07, N_2 = 0.09, N_3 = 0.14, N_4 = 0.61, N_5 = 0.09$

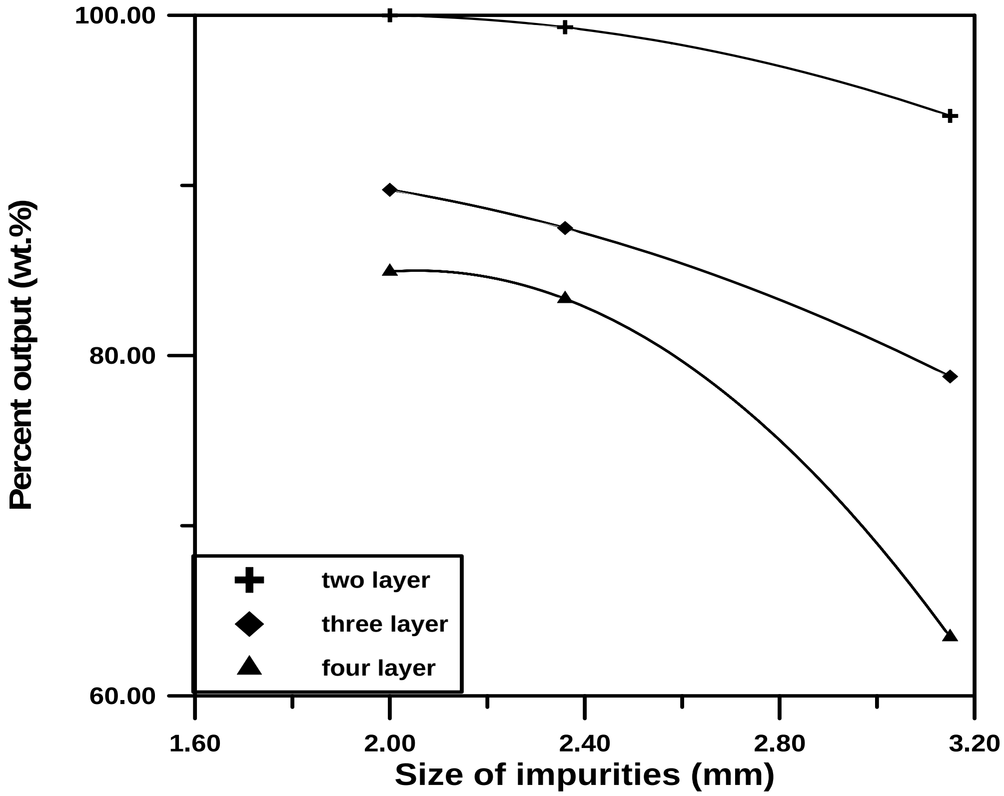

Figure 4.45 Size of Impurities Vs. Percent Output of Impurities
For: $\mathbf{N_1 = 0.035, N_2 = 0.045, N_3 = 0.09, N_4 = 0.68, N_5 = 0.15}$

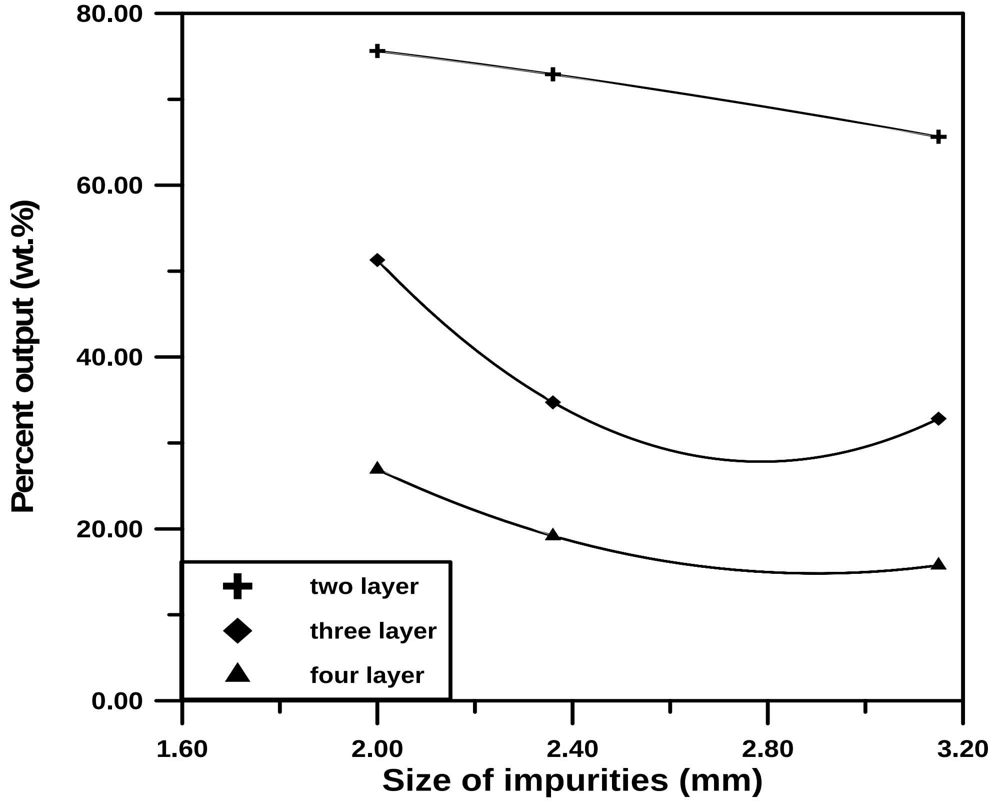

Figure 4.46 Size of Impurities Vs. Percent Output of Impurities
For: $\mathbf{N_1 = 0.55, N_2 = 0.15, N_3 = 0.15, N_4 = 0.14, N_5 = 0.01}$

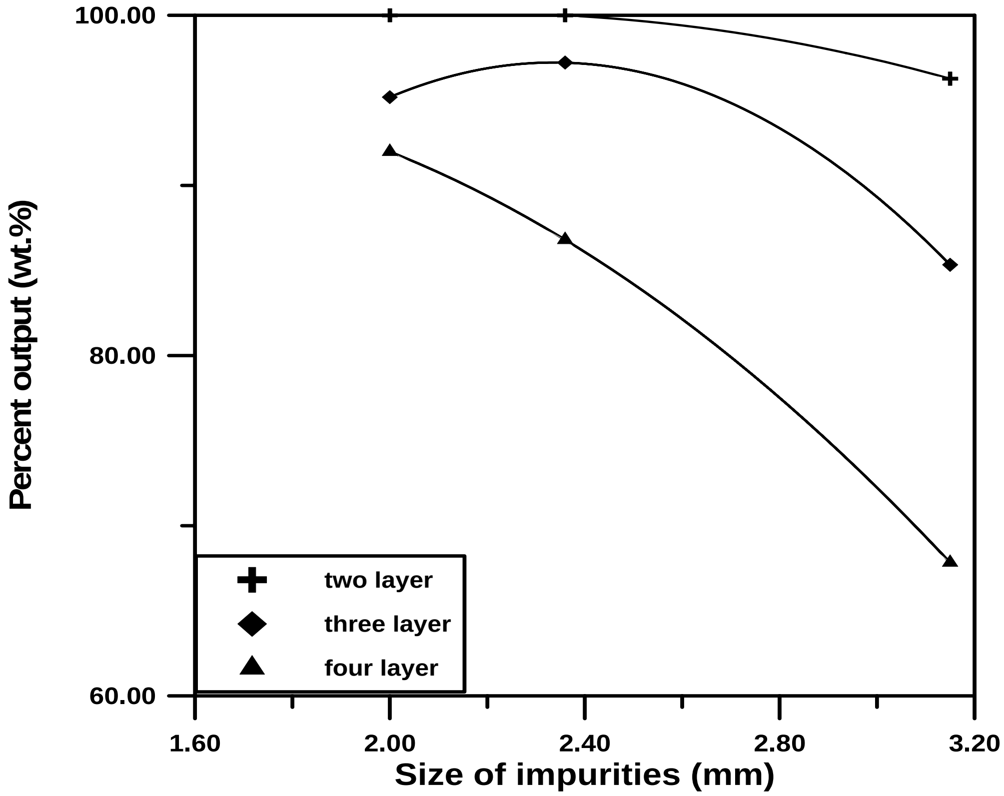

Figure 4.47 Size of Impurities Vs. Percent Output of Impurities For: $N_1 = 0.03, N_2 = 0.04, N_3 = 0.09, N_4 = 0.64, N_5 = 0.2$

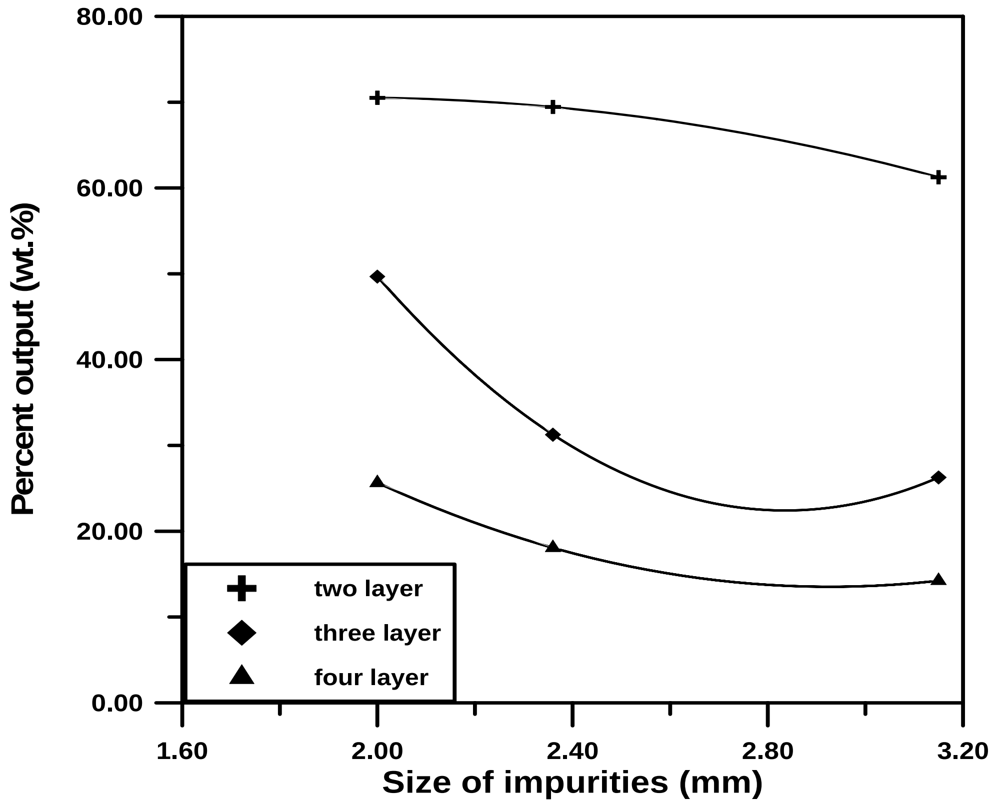

Figure 4.48 Size of Impurities Vs. Percent Output of Impurities For: $N_1 = 0.65, N_2 = 0.15, N_3 = 0.075, N_4 = 0.115, N_5 = 0.01$

4.5 Relationships Between Mean Pore Diameter and Porosity.

Porosity was calculated experimentally for each packed bed made from five sizes of spheres, also calculated in the experiments in case of two, three and four layers. Mean pore diameter due to number will be related with porosity for each packed bed made from five sizes of spheres. The curves of this relation are shown in figure 4.49 , and these curves show the relation between mean pore diameter and porosity,these figures show the proportionality between the mean pore diameter due to number and porosity for two, three and four layer respectively .The comparison between each curve for three types of impurities have been done in this section in each figure. It is obvious that when the numbers of the large spheres increase, there will be an increase in the porosity and these leads to the increase in the mean pore diameter.

The same relations were made for mean pore diameter due to length ($dc_m l$), surface area ($dc_m a$) and volume ($dc_m v$) .Figures show the curves of these relations are 4.50 to 4.52.

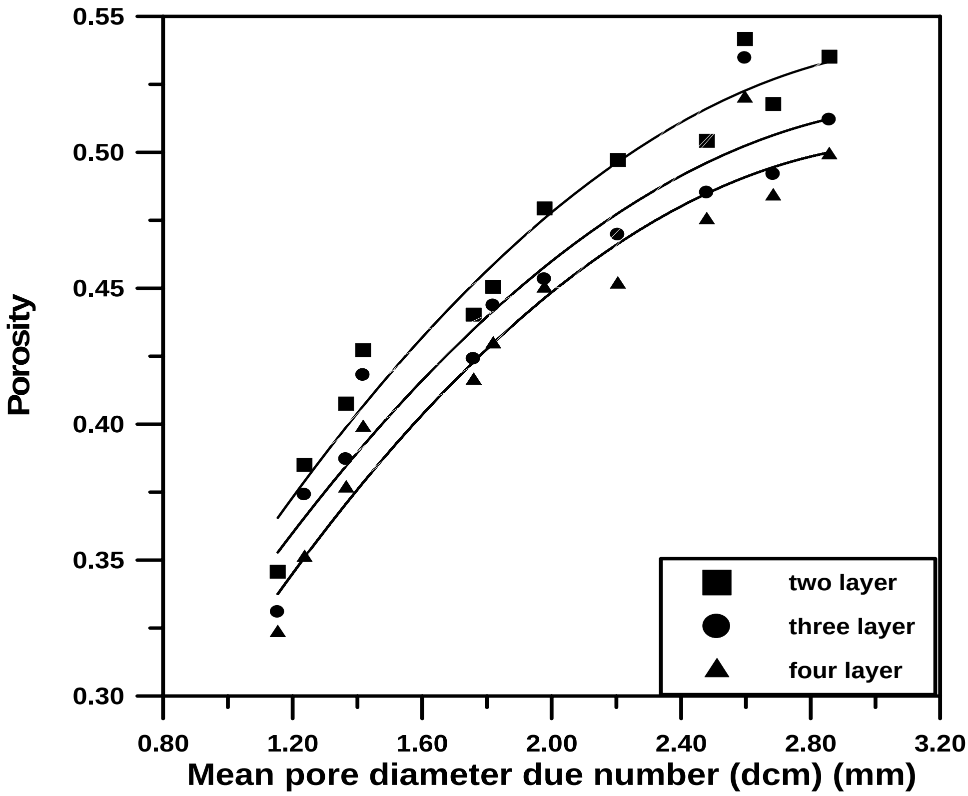

Figure 4.49 Mean Pore Diameter Due to Number Vs. Porosity

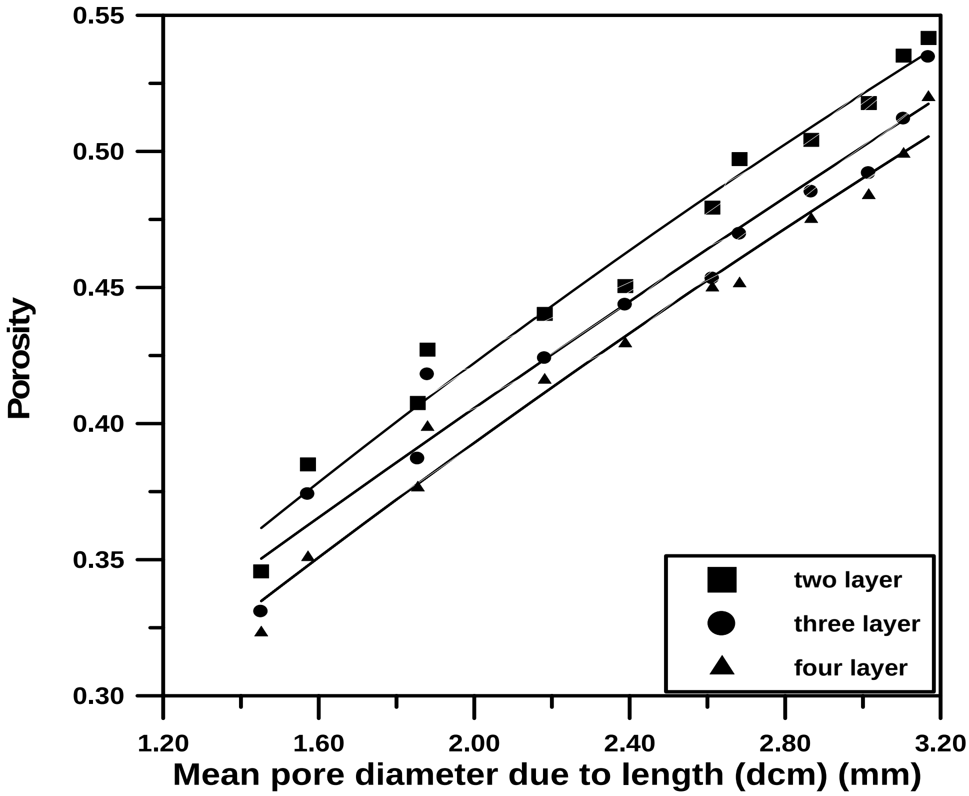

Figure 4.50 Mean Pore Diameter Due to Length Vs. Porosity

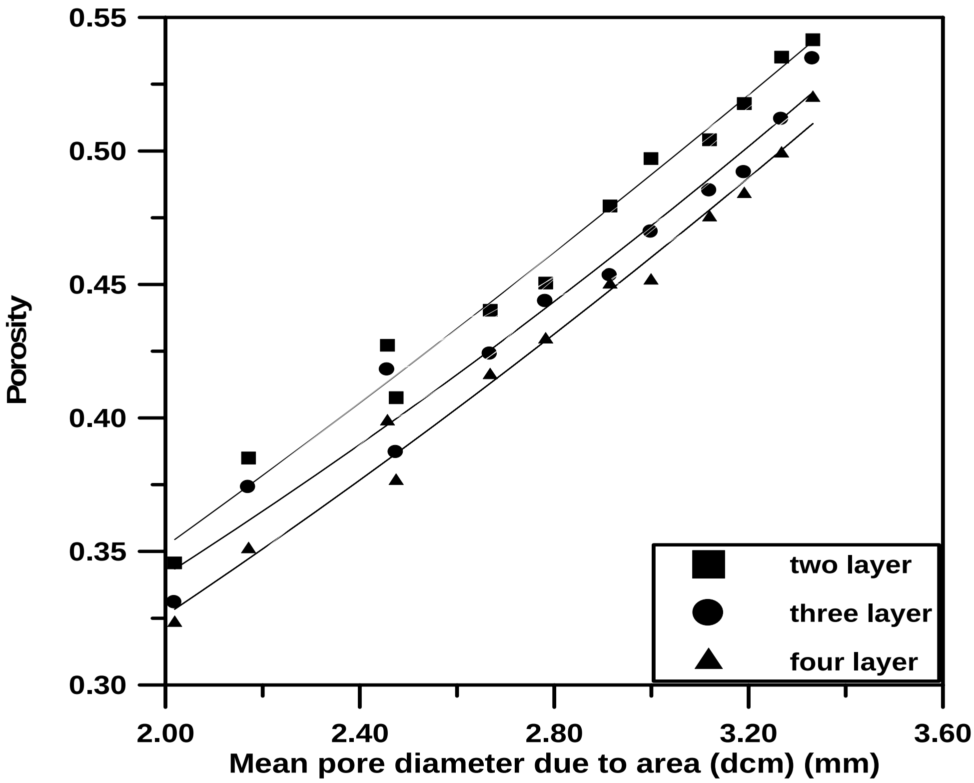

Figure 4.51 Mean Pore diameter Due to Area Vs. Porosity

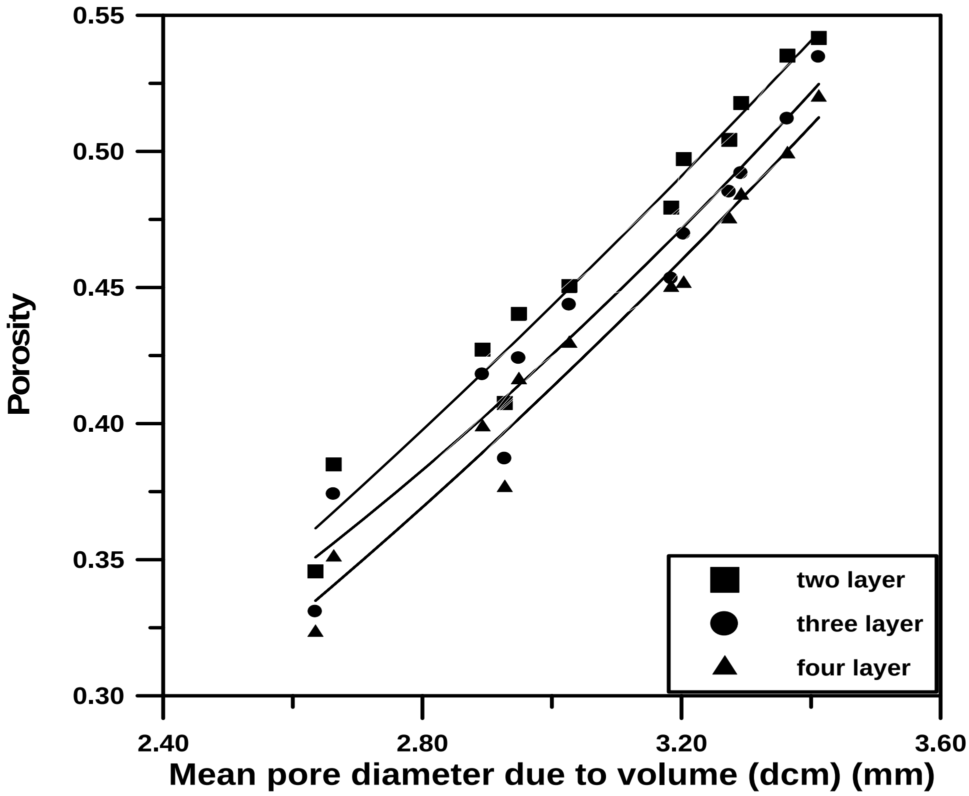

Figure 4.52 Mean Pore Diameter Due to Volume Vs. Porosity

4.6 Relationships Between Number of layers and Porosity.

In this section,The number of layers will be related with porosity calculated experimentally for each packed bed made from five sizes of spheres in case of two, three and four layers. The curves of this relation are shown in figure 4.53 .This figure show the proportionality between the number of layers and porosity .Its noticeable that when the number of layer increase a decrease in the value of porosity calculated occurs. Therefore the largest value of porosity occurs in the case of two layers and porosity decreased in three layer and a noticeable decrease in the case of four layers .

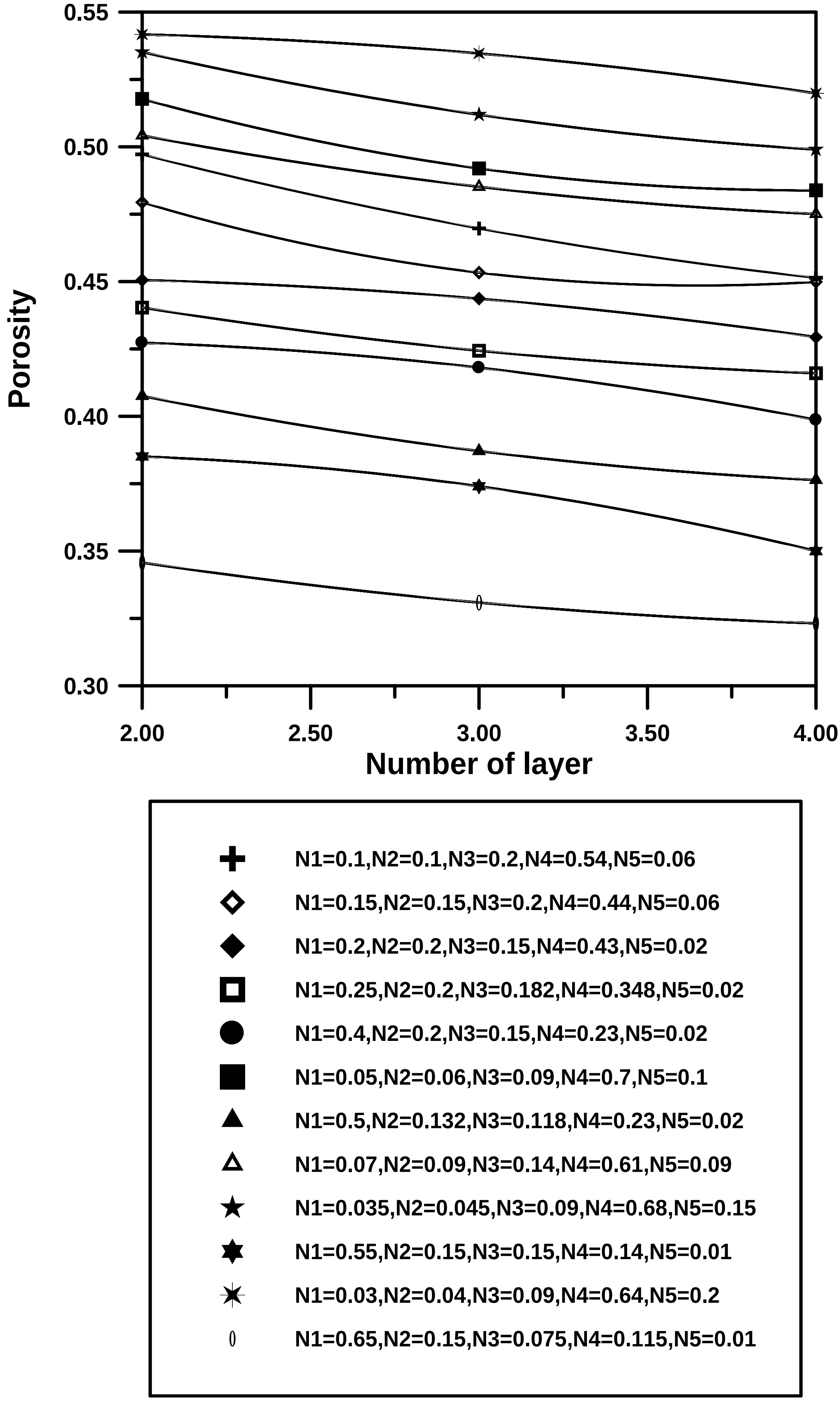

Figure 4.53 Numbers of Layers Vs. Porosity

4.7 Presentations (Porosity)

In appendix [B], the porosity for mono system of each group of spheres (6, 8, 10, 20, and 26mm) was calculated by using Furnas equation and the result was listed in table B.26 and also the porosity for binary system was calculated by using Jeschar equation and latif equation and listed the results in the tables B.27 to B.36.The experimental work is given in chapter three which contains determining porosity for mono system experimentally by taking certain number of each group of sphere listed in table 3.1 and measure the height of spheres in two the cylinder (12.9,6.4 cm) the height of sphere in the cylinder listed in table C.13 and then determine the porosity to determine the porosity and the results are listed in the table C.14.

Now this chapter will discuss and explain the results of ;(theoretical and experimental), suitable relation between porosity of mono system and diameter of the cylinder which contains the sphere and the porosity will be related with the diameter of sphere.

4.8 Derivation of Anew Empirical Equation for Mono System.

Furnas suggest the equation (2.9) for calculation the porosity of mono system which takes care of the effect of the container wall. Porosity was calculated in appendix[B] and the result listed in table B.26.

$$\varepsilon = 0.375 + 0.34\frac{d}{D} \quad \ldots\ldots. (2.9)$$

Table (4.1) presents the values calculated by equation (2.9) and the value of experimentally porosity .The absolute error between 0.3% & 2.59 %.

Table 4.1 Calculated Values of Porosity Using Furnas Equation for Mono System as Compared to The Porosity Determined Experimentally with Absolute Error.(in Cylinder of Diameter 12.9 cm)

No.	Porosity determined experimentally	Porosity calculated using Furnas equation	Absolute error
1	0.395	0.3908	0.0106
2	0.4	0.39608	0.0098
3	0.412	0.4013	0.0259
4	0.429	0.4277	0.003
5	0.452	0.4435	0.0187

The modification of equation (2.9) under consideration of the porosity the present work leads to equation (4.1):

$$\varepsilon_f = 0.418 + 0.34\frac{d}{D} \quad \ldots\ldots\ldots(4.1)$$

Where (0.418) the average value of experimental porosity of the present packing .The absolute error lies now between 7.63 % & 9.82%.

Table 4.2 Calculated Values Porosity Using Modified Furnas Equation for Mono System as Compared to The Porosity Determined Experimentally with Absolute Error.(in Cylinder of Diameter 12.9 cm).

No.	Porosity determined experimentally	Porosity calculated modified equation	Absolute error
1	0.395	0.4338	0.0982
2	0.4	0.43908	0.0977
3	0.412	0.4443	0.07839
4	0.429	0.4707	0.0972
5	0.452	0.4865	0.0763

When the result of the present experimental table plotted as shown in
Figure 4.54 .The empirical equation (4.2) and (4.3)could be derived respectively.

$$\varepsilon_f = 0.38017 + 0.3458\left(\frac{d}{D}\right) \quad \ldots\ldots\ (4.2)$$

$$\varepsilon_f = 0.3475 + 1.406\left(\frac{d}{D}\right) - 9.86\left(\frac{d}{D}\right)^2 + 27.11\left(\frac{d}{D}\right)^3 \quad \ldots\ldots\ldots(4.3)$$

Empirical equation which represent our research as linear equation (4.2) and (4.3) equation was in form of polynomial relation which can be used for further research under consideration of the effect of the surface area and the volume of the bed particle and the container represent by $\left(\frac{d}{D}\right)^2$ and $\left(\frac{d}{D}\right)^3$.

Table (4.3) presents the values calculated by equation (2.9) and porosity determined experimentally. The absolute error between 1.86 % & 4.16 %.

Table 4.3 Calculated Values of Porosity Using Furnas Equation for Mono System as Compared to The Porosity Determined Experimentally with Absolute Error.(in Cylinder of Diameter 6.4 cm)

No.	Porosity determined experimentally	Porosity calculated using Furnas equation	Absolute error
1	0.4146	0.4069	0.0186
2	0.43	0.4175	0.02907
3	0.4466	0.428	0.0416
4	0.4905	0.4812	0.01896
5	0.5232	0.5131	0.0193

The modification of equation (2.9) under consideration of the porosity the present work leads to equation (4.4):

$$\varepsilon_f = 0.461 + 0.34\frac{d}{D} \quad \ldots\ldots.(4.4)$$

Where (0.461) is the average value of experimental porosity of the present packing .The absolute error lies now between 1.888 % & 1.451%.

Table 4.4 Calculated Values Porosity Using Modified Furnas Equation for Mono System as Compared to The Porosity Calculated Experimentally with Absolute Error.(in Cylinder of Diameter 6.4 cm).

No.	Porosity determined experimentally	Porosity calculated using Furnas equation	Absolute error
1	0.4146	0.4929	0.1888
2	0.43	0.5035	0.1709
3	0.4466	0.5141	0.1511
4	0.4905	0.56725	0.1565
5	0.5232	0.5991	0.1451

When the result of the present experimental table plotted as shown in Figure 4.55 the empirical equation (4.5) and (4.6) could be derived respectively.

$$\varepsilon_f = 0.38829 + 0.3319\left(\frac{d}{D}\right) \text{ .... } (4.5)$$

$$\varepsilon_f = 0.33318 + 1.406\left(\frac{d}{D}\right) - 9.86\left(\frac{d}{D}\right)^2 + 27.11\left(\frac{d}{D}\right)^3 \text{ ....}(4.6)$$

Empirical equation which represent our research as linear equation(4.5) and equation (4.6) was in form of polynomial relation which can be used for further research under consideration of the effect of the surface area and the volume of the bed particle and the container represent by $\left(\frac{d}{D}\right)^2$ and $\left(\frac{d}{D}\right)^3$.

The absolute error listed in the above table may be due to following reasons:

1- The shape of the particles.
2- The diameter ratio (d/D).
3- The packing method.
4- The packing tools.

5.9 Relation Between The Porosity and The Diameter of Spheres.

The porosity for mono system will be related with the diameter of spheres which made the packed bed.

The curves of this relation are shown in figures 4.54 and 4.55.In the experimental part the group of spheres of diameter 6mm was packed in the cylinder and determined the porosity .The same procedure repeated for 8, 10,20and 26.It is noticeable that the porosity is larger in the case of 8mm than the porosity in the case of 6mm and the porosity is larger in the case of 10 mm than the porosity in the case of 8mm and so on, therefore it is obvious, that when the diameter of the spheres which made the packed bed increased the porosity will be increased.

In the theoretical part the value of porosity calculated by using Furnas equation will be increased when the diameter of the spheres which made the packed bed increased ,because the ratio of d/D will be increased , the porosity will be increased. The porosity increased when the diameter of spheres which made the packed bed increased.

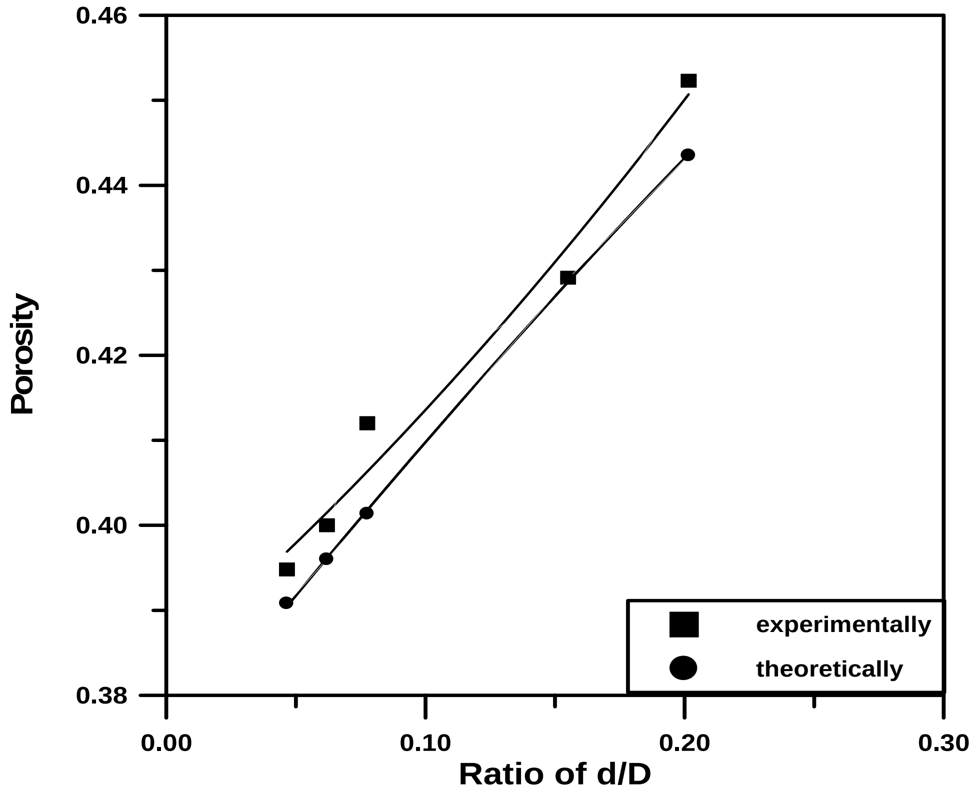

Figure 4.54 Ratio of d/D vs. Porosity in The Cylinder of Diameter 12.9 cm

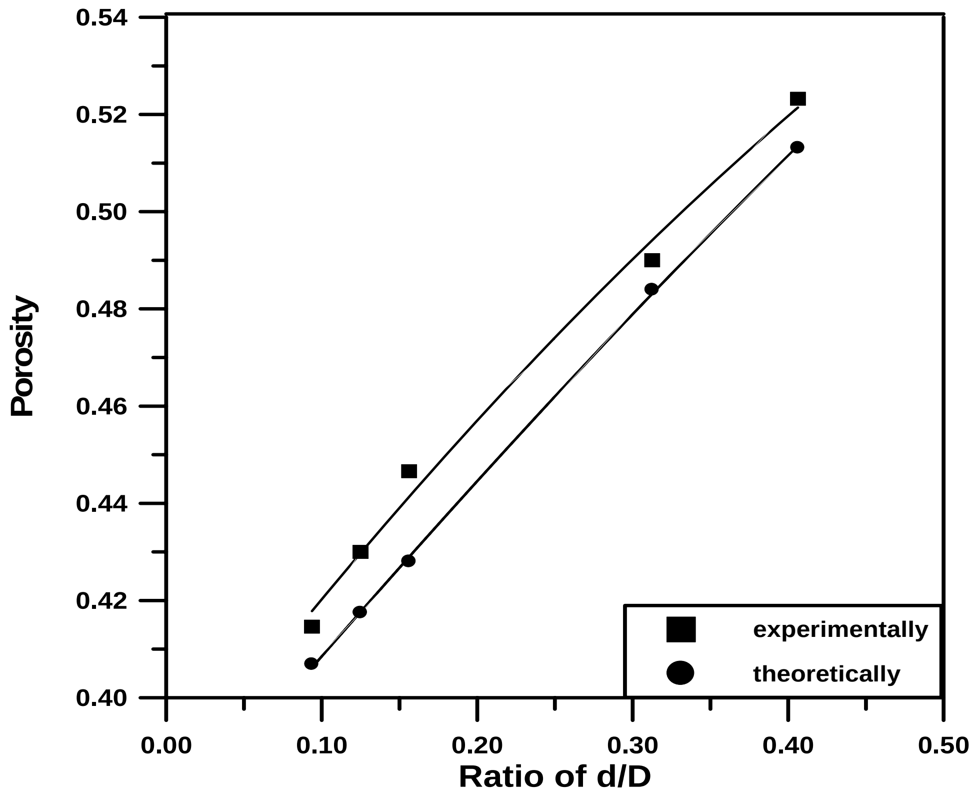

Figure 4.55 Ratio of d/D vs. Porosity in The Cylinder of Diameter 6.4 cm

4.10 Relation Between The Porosity and The Diameter of Cylinder which Contains The Sphere.

The experimental work in chapter four was done first in the cylinder of diameter 12.9 and the same procedure was repeated with cylinder of 6.4 cm.

The curves of this relation are shown in figures 4.56 to 4.57.The values of porosity calculated by Furnas are taken from the table B.26 and the values of porosity determined experimentally are taken from the table C.14.

The figures 4.56 and 4.57 show the proportionality between the porosity and the diameter of the cylinder .It is obvious in the experimental part the value of porosity in cylinder of diameter 12.9cm is smaller than the value of the porosity in the cylinder of diameter 6.4cm .As a result the height of number of sphere in the cylinder of diameter 6.4 cm will be more than the height of the same number of sphere in the cylinder of 12.9 cm ,therefore the value of porosity will be larger.

In the theoretical part also the value of porosity in cylinder of diameter 12.9cm is smaller than the value of the porosity in the cylinder of diameter 6.4cm,because the ratio of d/D will be larger in the case of cylinder of diameter 6.4cm.This ratio will be effected in the value of porosity that calculated by Furnas equation ,the value of porosity will be increased when the diameter of the cylinder decreased.

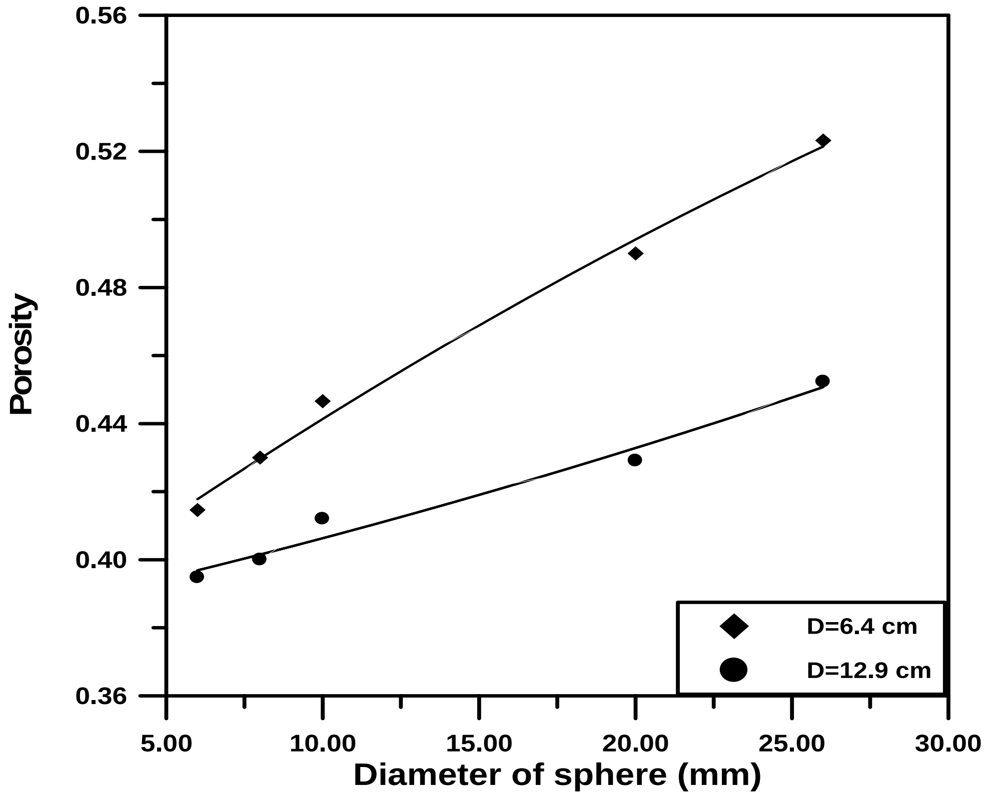

Figure 4.56 Diameter of Sphere Vs. Porosity Determined Experimentally with Cylinder Diameter (6.4,12.9) Respectively.

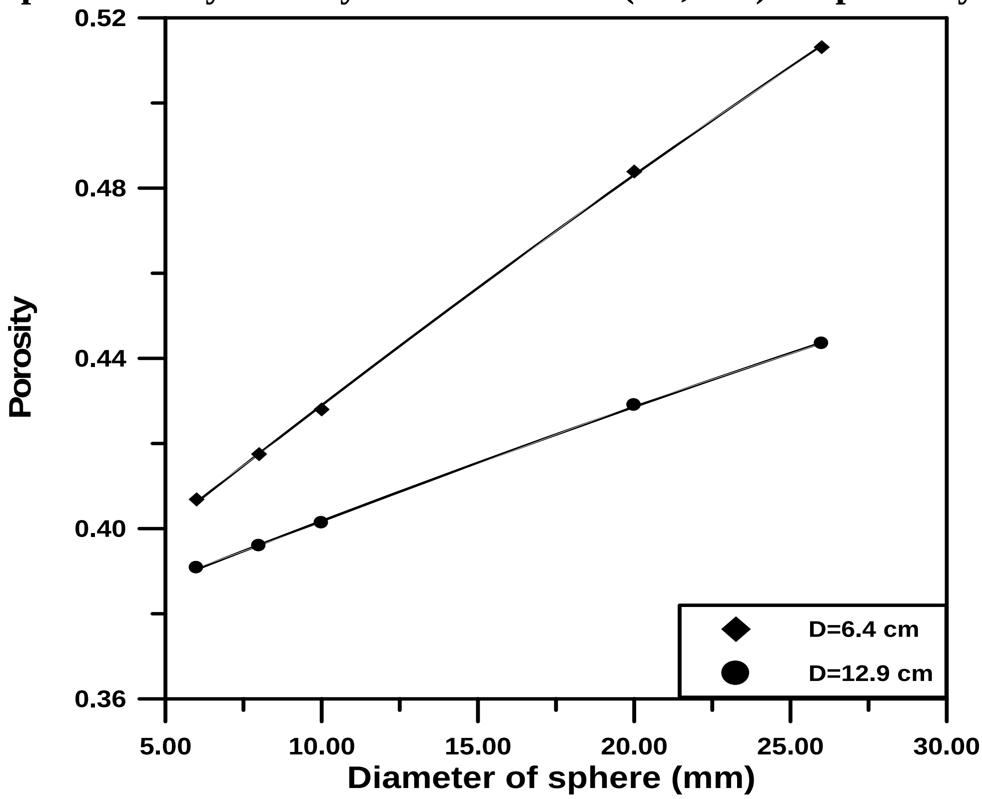

Figure 4.57 Diameter of Sphere Vs. Porosity Calculated Theoretically with Cylinder Diameter (6.4,12.9) Respectively

4.11 Derivation of Anew Empirical Equation for Binary System.

Porosity for binary system calculated theoretically by using Jeschar equation and Latif equation and the results was listed in appendix [B] in tables B.27 to B.36 and figures shown from 4.58 to 4.59 .In appendix [C] porosity calculated experimentally and the results was listed in tables C.14 to C.24 figures shown form 4.60 to 4.69.

Now theoretical results compared with experimental result and then absolute results was calculated. The results was listed in tables from table 4.5 to 4.14 .It is clear from the tables Jeschar equation give more acceptable result than Latif equation .The absolute error in Jeschar equation is low its range 4.85% to 17 % but in Latif equation absolute error is high its range from 0.985% to 68.3% .So Latif equation was modified under consideration of the porosity of the present work in order to get more acceptable results and the range of absolute error 0.04% to 13.8% .The results of modified equation was listed in tables from 4.15 to 4.24.

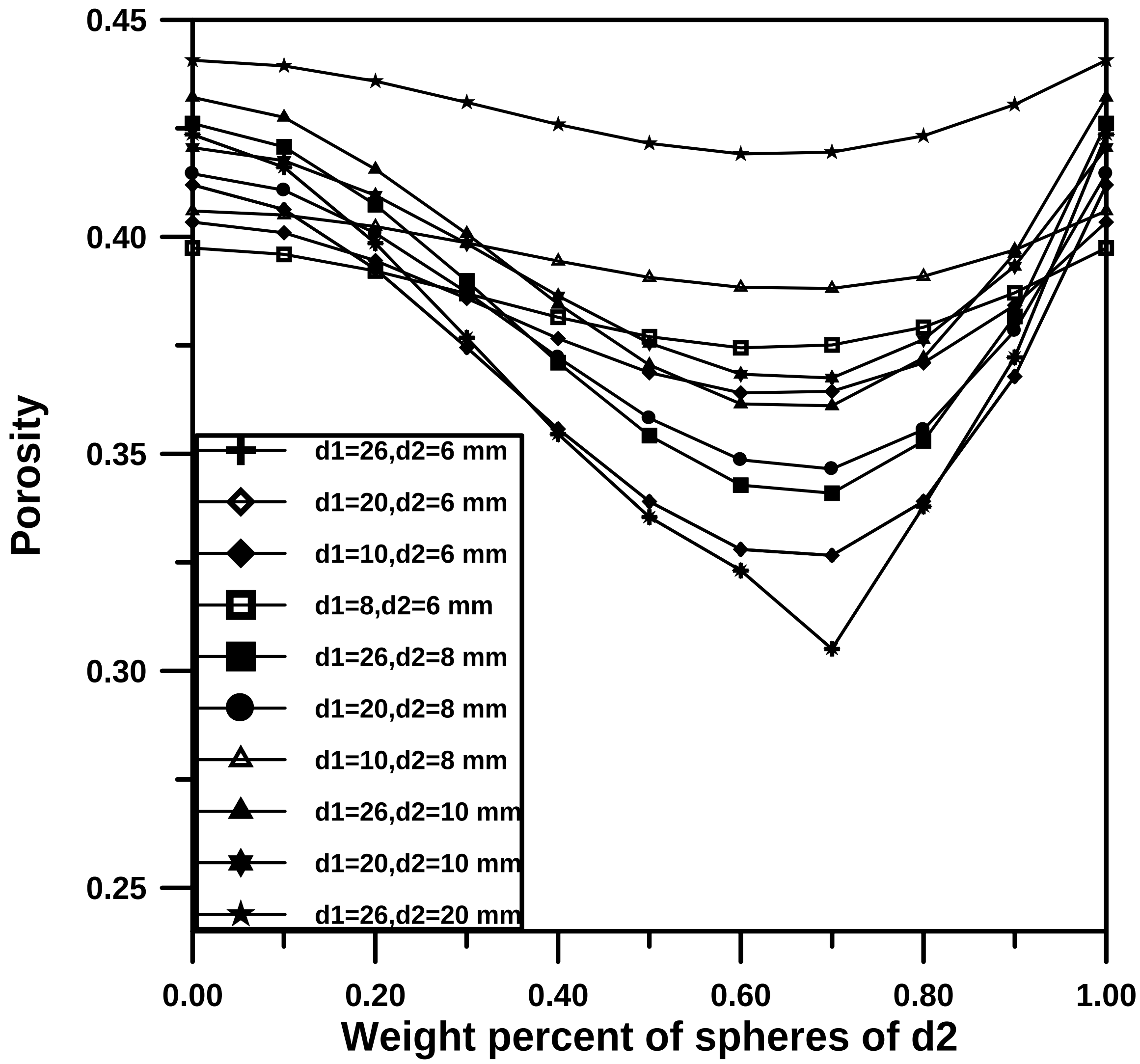

Figure 4.58 Porosity Calculated in Jeschar Equation Vs. Weight Percent of Spheres of d2 for Binary System

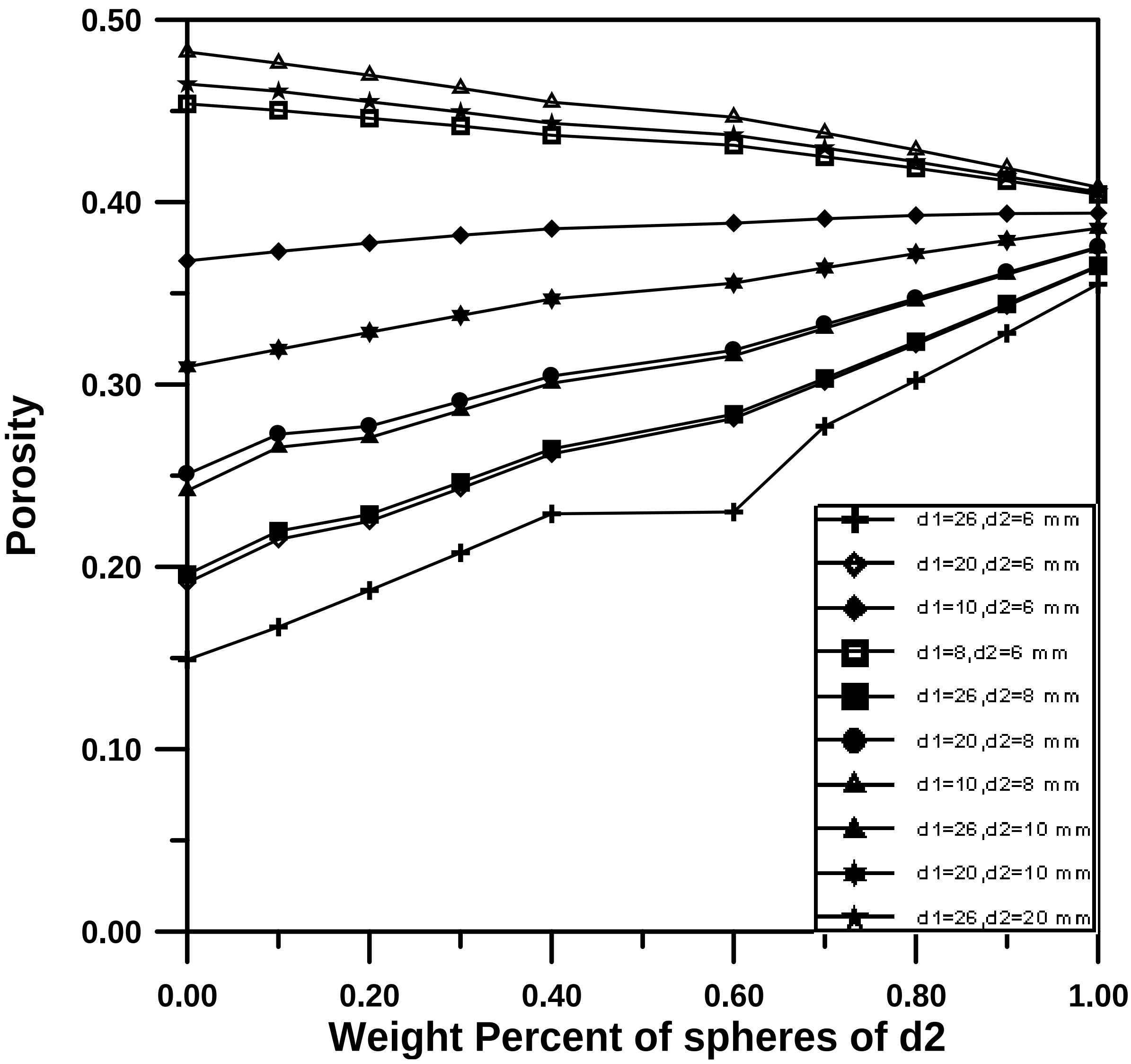

Figure 4.59 Porosity Calculated in Latif Equation Vs. Weight Percent of Spheres of d2 for Binary System .

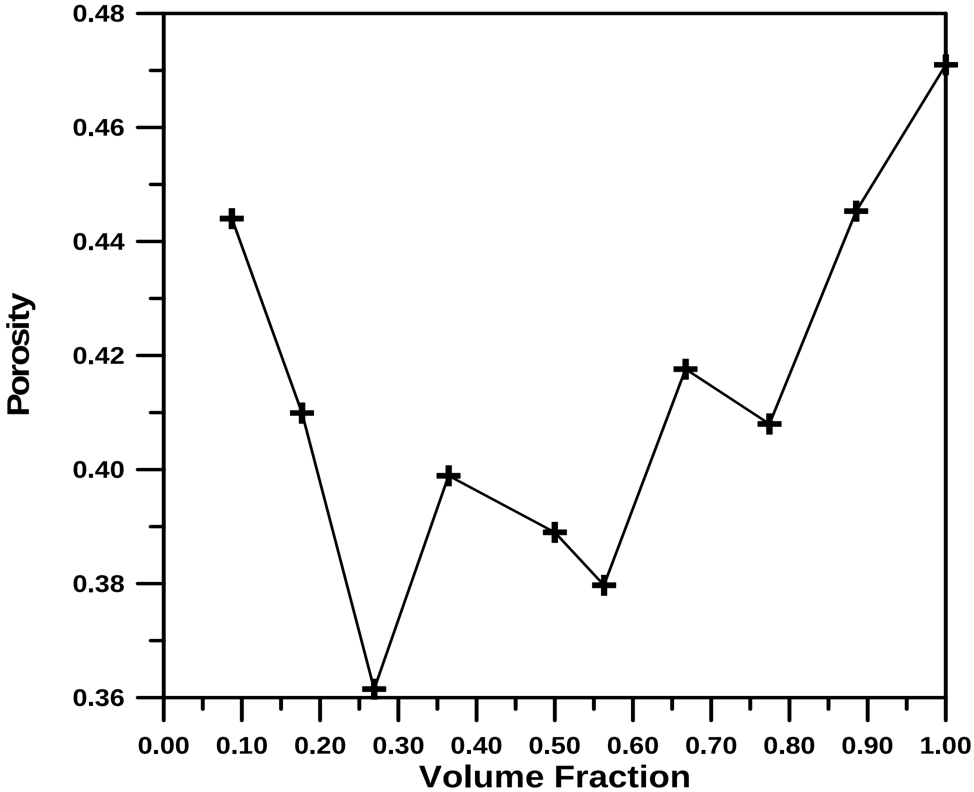

Fig 4.60 Experimental Porosity for Binary System(d_1=26mm,d_2=6 mm) Vs. Volume Fraction

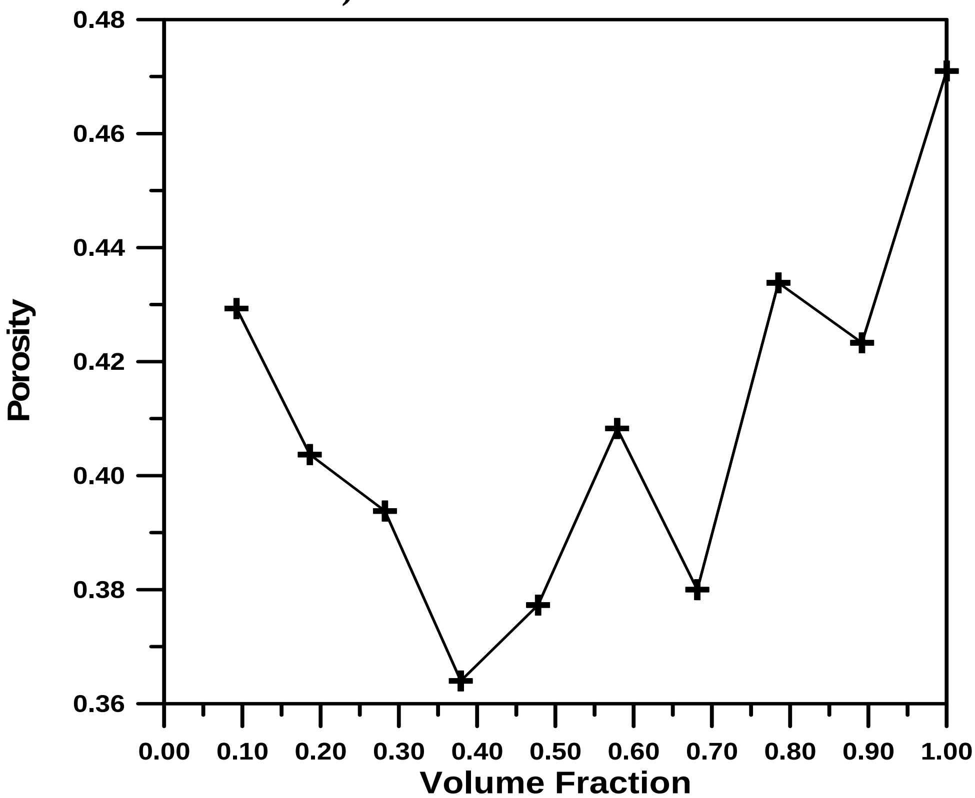

Fig 4.61 Experimental Porosity for Binary System(d_1=20mm,d_2=6 mm) Vs. Volume Fraction

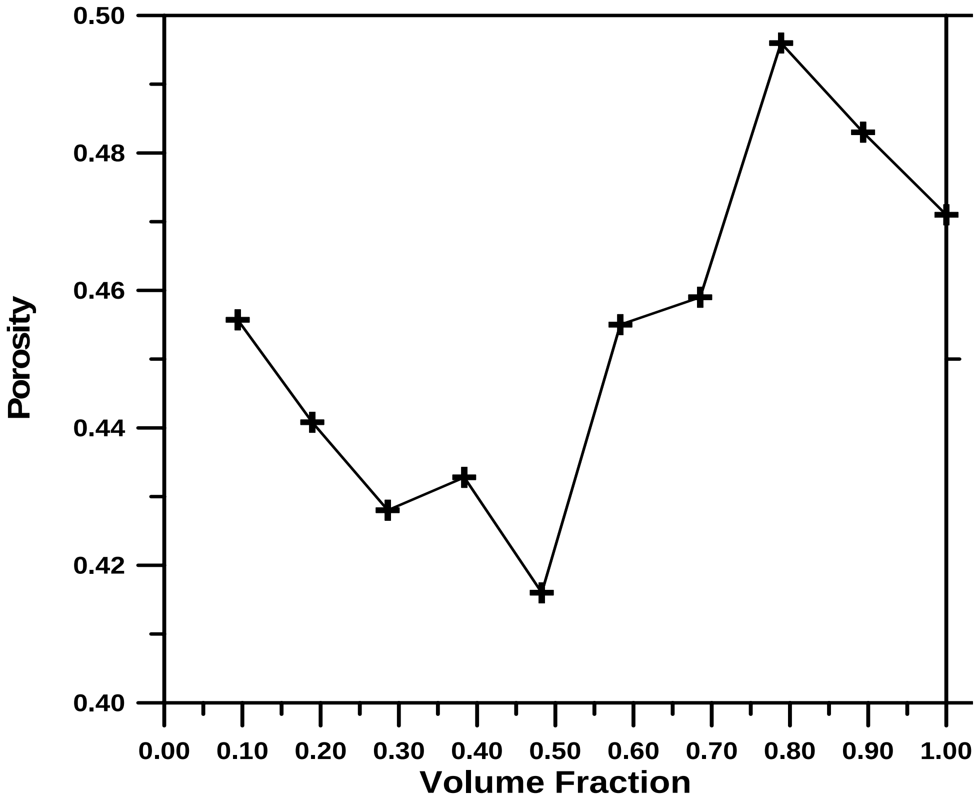

Fig 4.62 Experimental Porosity for Binary System(d_1=10mm, d_2=6 mm) Vs. Volume Fraction

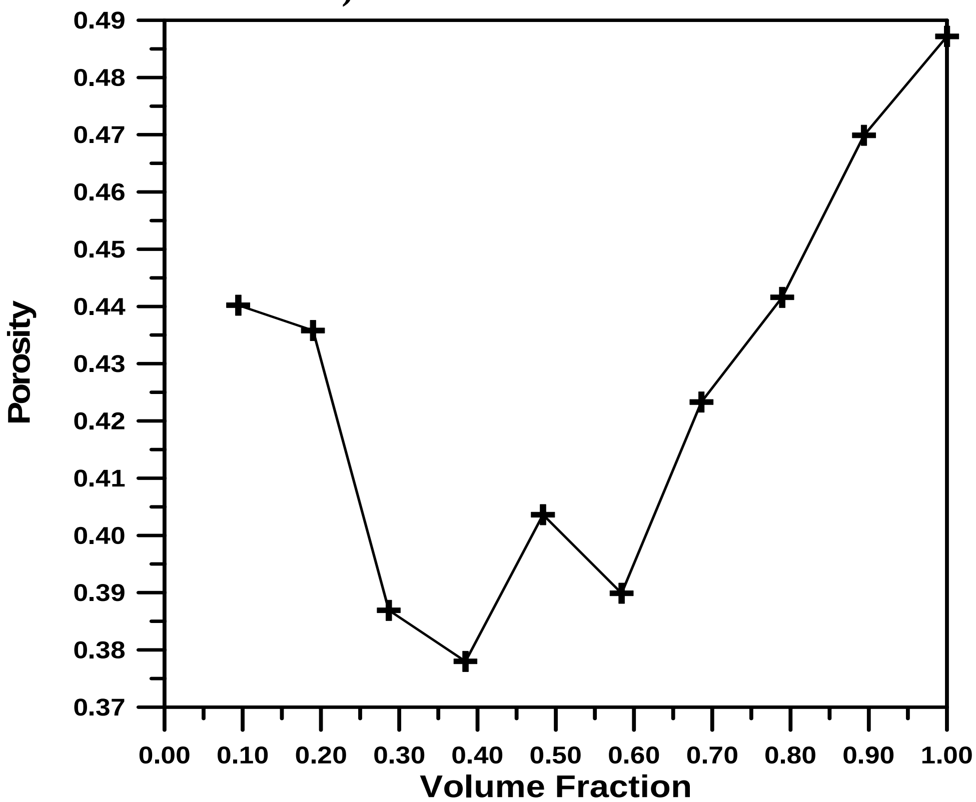

Fig 4.63 Experimental Porosity for Binary System(d_1=8mm, d_2=6 mm) Vs. Volume Fraction

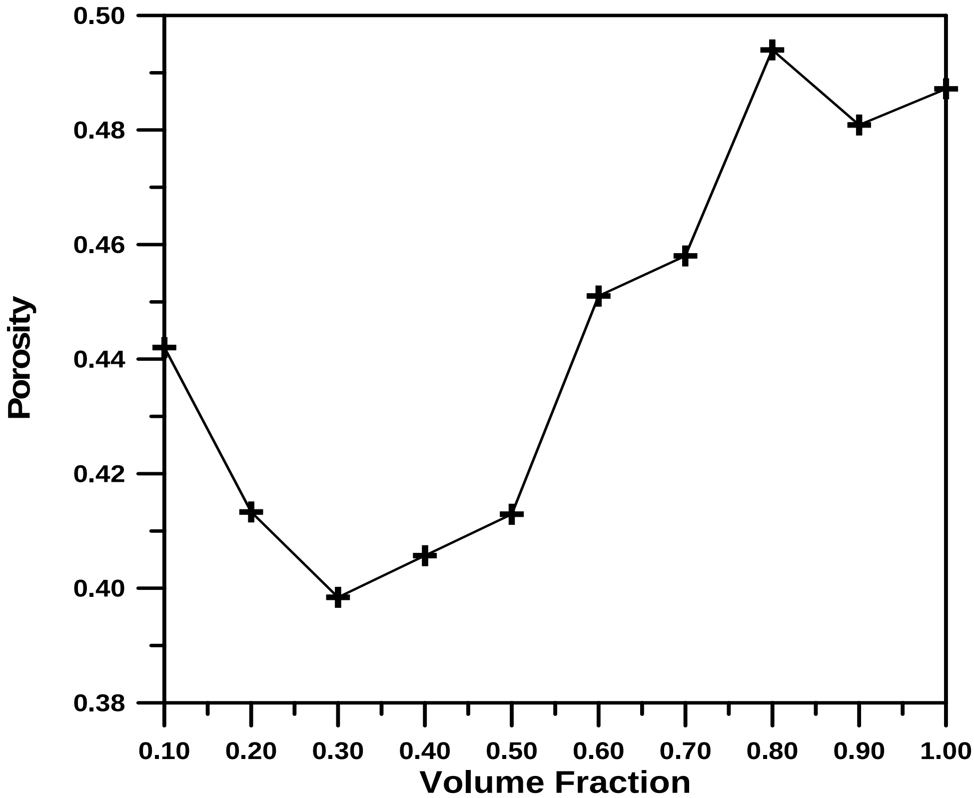

Fig 4.64 Experimental Porosity for Binary System(d_1 =26 mm, d_2 =8 mm) Vs. Volume Fraction

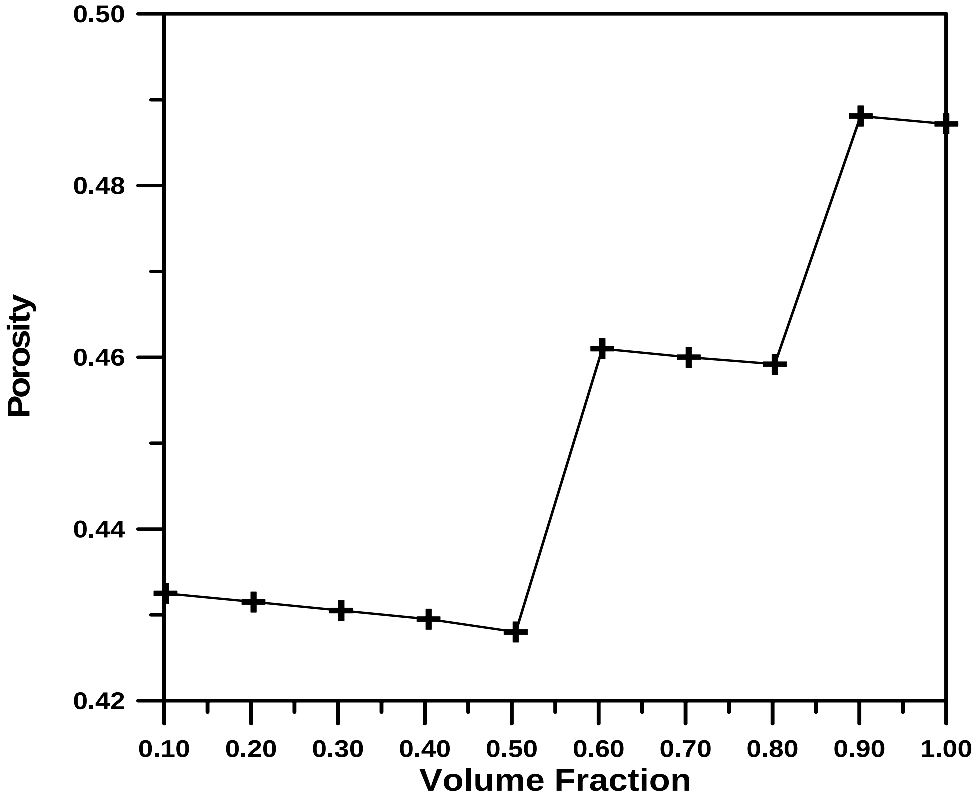

Fig 4.65 Experimental Porosity for Binary System(d_1 =20 mm, d_2 =8 mm) Vs. Volume Fraction

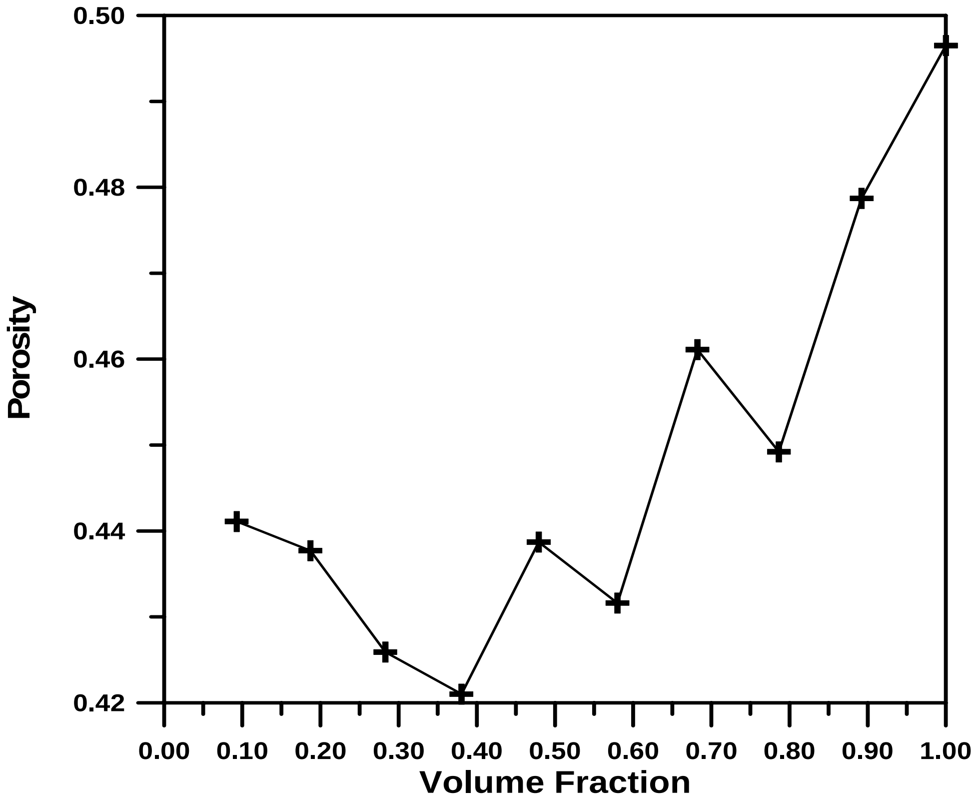

Fig 4.66 Experimental Porosity for Binary System(d_1=10 mm, d_2=8 mm) Vs. Volume Fraction

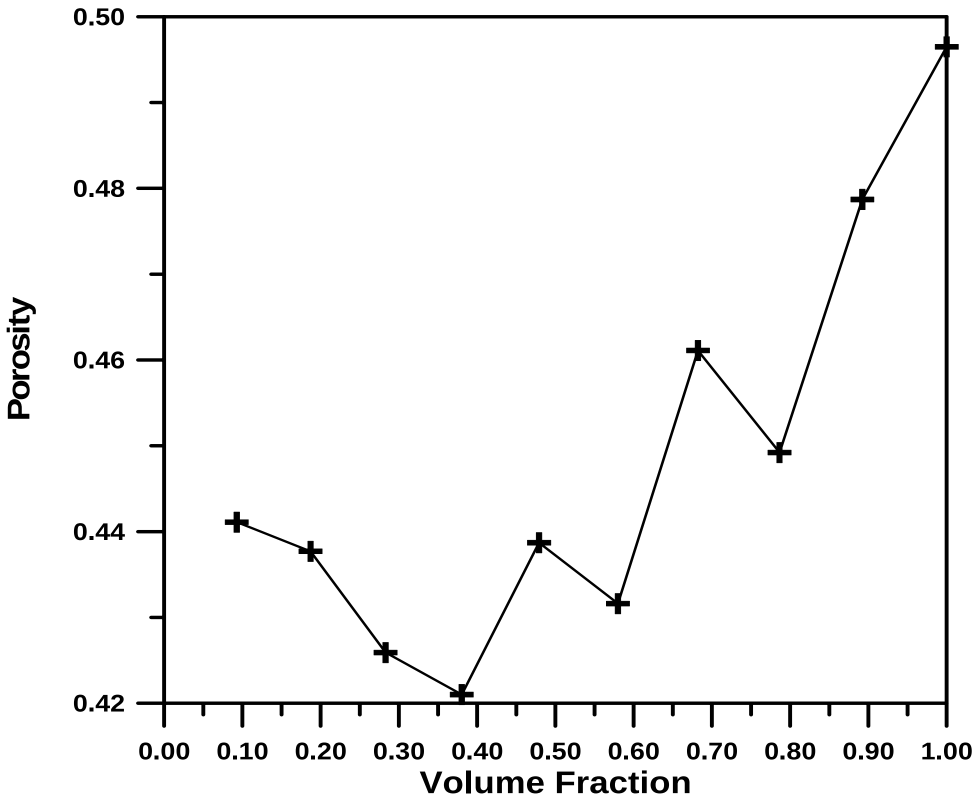

Fig 4.67 Experimental Porosity for Binary System(d_1=26 mm, d_2=10 mm) Vs. Volume Fraction

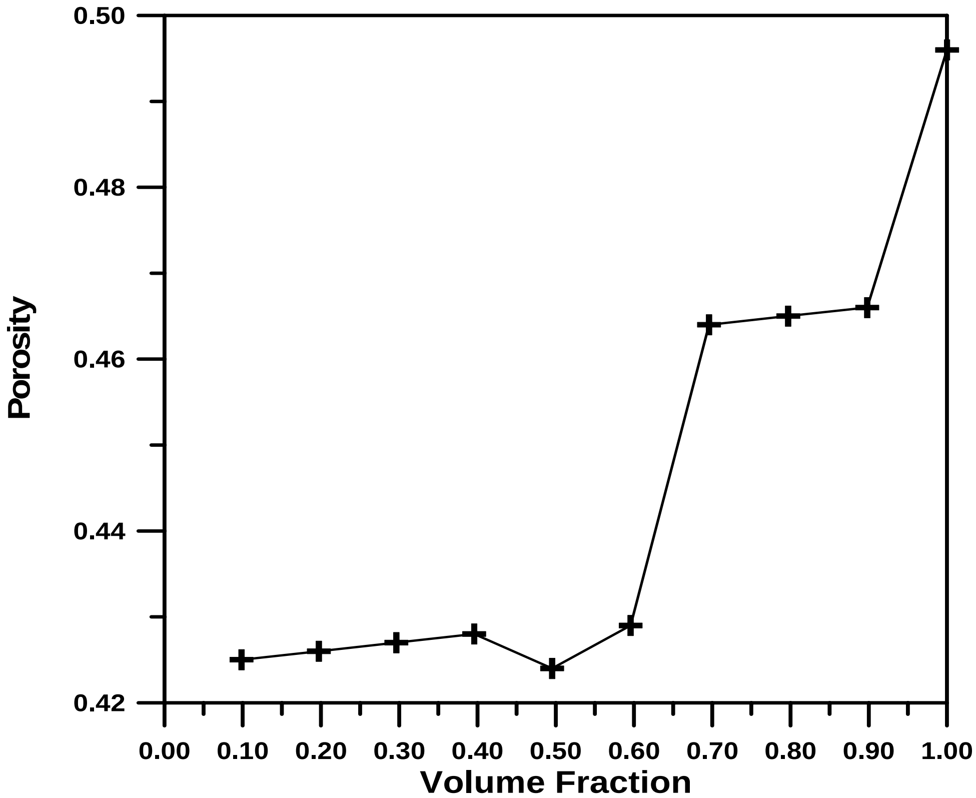

Fig 4.68 Experimental Porosity for Binary System(d_1 =20 mm, d_2 =10 mm) Vs. Volume Fraction

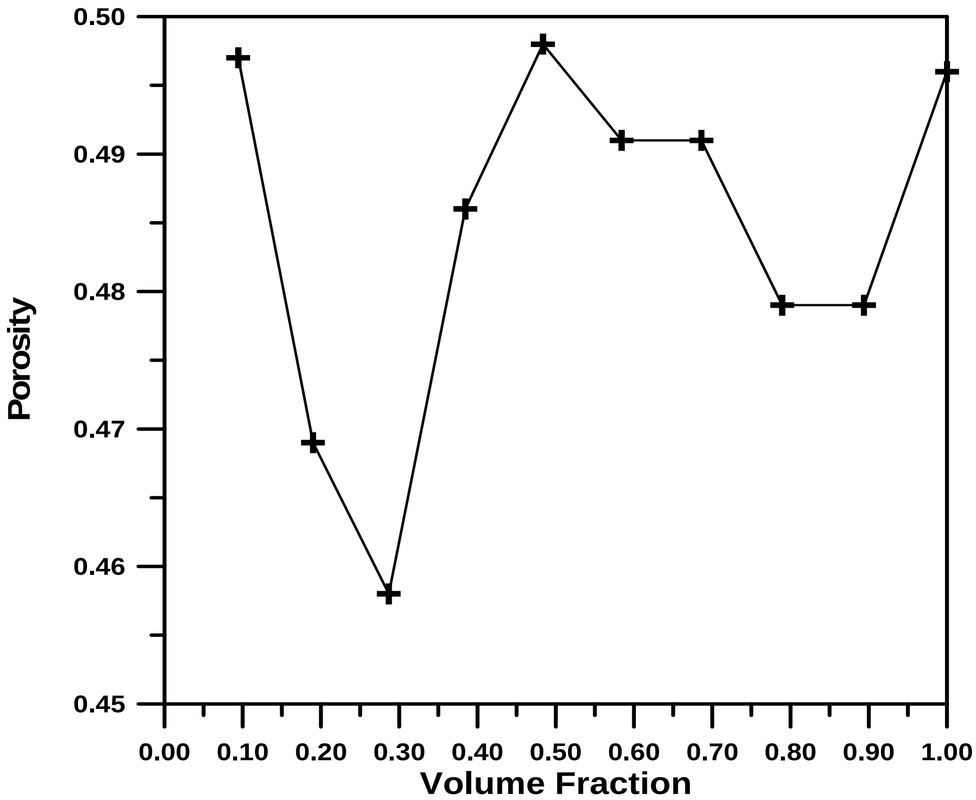

Fig 4.69 Experimental Porosity for Binary System(d_1 =26 mm, d_2 =20 mm) Vs. Volume Fraction

Table 4.5 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=26,d2=6)

V_2	Porosity determined experimentally	Porosity calculated by using Jeschar equation	Absolute error	Porosity calculated by using Latif equation	Absolute error
1	0.471	0.4236	0.1	0.1492	0.6832
0.8855	0.4454	0.416	0.066	0.1675	0.624
0.7746	0.408	0.3985	0.0233	0.1869	0.5419
0.6672	0.4176	0.3767	0.0979	0.2078	0.5023
0.5631	0.3797	0.3545	0.066	0.2297	0.395
0.5	0.3893	0.3354	0.1384	0.2439	0.3735
0.3642	0.3989	0.3231	0.19	0.277	0.3055
0.2691	0.3616	0.305	0.156	0.3023	0.1639
0.1768	0.4099	0.3379	0.1756	0.3285	0.198
0.087	0.4443	0.3722	0.1622	0.355	0.2

Table 4.6 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=20,d2=6)

V_2	Porosity Determined Experimentally	Porosity Calculated by Using Jeschar Equation	Absolute Error	Porosity Calculated by Using Latif Equation	Absolute Error
1	0.471	0.41196	0.125	0.1912	0.594
0.8919	0.4233	0.4063	0.04	0.2154	0.4911
0.7858	0.4338	0.3925	0.095	0.225	0.481
0.6815	0.38	0.3745	0.0145	0.2431	0.36
0.579	0.4083	0.3557	0.1288	0.2619	0.358
0.4783	0.3773	0.339	0.102	0.2813	0.2544
0.3794	0.364	0.3279	0.099	0.3014	0.172
0.2821	0.3938	0.3266	0.1706	0.322	0.1823
0.1865	0.4037	0.339	0.16	0.343	0.1503
0.0925	0.429	0.3678	0.125	0.3644	0.2566

Table 4.7 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=10,d2=6)

V_2	Porosity Determined Experimentally	Porosity Calculated by Using Jeschar Equation	Absolute Error	Porosity Calculated by Using Latif Equation	Absolute Error
1	0.471	0.4034	0.1435	0.3677	0.219
0.8936	0.4826	0.4009	0.169	0.3729	0.227
0.7887	0.496	0.3945	0.149	0.3776	0.186
0.6853	0.459	0.3858	0.16	0.38185	0.169
0.5833	0.455	0.3765	0.17	0.38549	0.152
0.4828	0.4161	0.3687	0.114	0.38855	0.066
0.3836	0.4328	0.36403	0.159	0.39097	0.0967
0.2857	0.428	0.3644	0.149	0.3927	0.0826
0.1892	0.4408	0.37095	0.158	0.3937	0.107
0.09396	0.4557	0.3842	0.157	0.394	0.135

Table 4.8 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=8,d2=6)

V_2	Porosity Determined Experimentally	Porosity Calculated by Using Jeschar Equation	Absolute Error	Porosity Calculated by Using Latif Equation	Absolute Error
1	0.471	0.3974	0.156	0.45386	0.0364
0.8919	0.483	0.3959	0.179	0.45035	0.067
0.7858	0.462	0.39212	0.15	0.446	00339
0.6815	0.457	0.3869	0.153	0.4418	0.0332
0.579	0.434	0.3815	0.121	0.4367	0.0064
0.4783	0.447	0.3769	0.157	0.4312	0.0354
0.3738	0.442	0.37441	0.154	0.42488	0.0396
0.28209	0.438	0.3751	0.143	0.4187	0.0438
0.1865	0.449	0.3791	0.157	0.41169	0.0849
0.0925	0.462	0.3871	0.162	0.40417	0.125

Table 4.9 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=26,d2=8)

V_2	Porosity Determined Experimentally	Porosity Calculated by Using Jeschar Equation	Absolute Error	Porosity Calculated by Using Latif Equation	Absolute Error
1	0.4872	0.4262	0.125	0.1958	0.598
0.894	0.4699	0.4208	0.105	0.2195	0.533
0.7894	0.4416	0.4074	0.0774	0.2287	0.482
0.6862	0.4233	0.3898	0.079	0.2463	0.4177
0.5843	0.3899	0.371	0.0485	0.2646	0.321
0.4838	0.4036	0.3542	0.122	0.2836	0.297
0.3845	0.378	0.3428	0.093	0.3033	0.198
0.2866	0.3869	0.3409	0.119	0.3235	0.164
0.1898	0.4358	0.3529	0.1902	0.34409	0.2104
0.0943	0.4402	0.3816	0.133	0.36508	0.1706

Table 4.10 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=20,d2=8)

V_2	Porosity Determined Experimentally	Porosity Calculated by Using Jeschar Equation	Absolute Error	Porosity Calculated by Using Latif Equation	Absolute Error
1	0.4872	0.4146	0.149	0.2508	0.4852
0.9	0.4809	0.4107	0.146	0.2727	0.432
0.8	0.494	0.4008	0.189	0.277	0.439
0.7	0.458	0.3872	0.154	0.2907	0.3652
0.6	0.451	0.3722	0.175	0.3046	0.325
0.5	0.4129	0.3582	0.132	0.3187	0.228
0.4	0.4057	0.3486	0.1407	0.3329	0.179
0.3	0.3984	0.3465	0.1302	0.3472	0.1285
0.2	0.4133	0.3555	0.139	0.3614	0.126
0.1	0.442	0.3783	0.144	0.3754	0.1507

Table 4.11 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=10,d2=8)

V_2	Porosity Determined Experimentally	Porosity Calculated by Using Jeschar Equation	Absolute Error	Porosity Calculated by Using Latif Equation	Absolute Error
1	0.4872	0.406	0.1666	0.4824	0.00985
0.9016	0.4881	0.405	0.1702	0.4762	0.0243
0.8028	0.4592	0.4024	0.124	0.4696	0.0226
0.7037	0.46	0.3986	0.133	0.4625	0.00543
0.6043	0.461	0.3944	0.144	0.4548	0.0134
0.5044	0.428	0.39064	0.0874	0.4467	0.0437
0.4043	0.4295	0.3883	0.0959	0.4379	0.0196
0.3037	0.4305	0.3881	0.0985	0.4286	0.0044
0.2029	0.4315	0.3909	0.094	0.4187	0.0297
0.1016	0.4325	0.3969	0.0823	0.4082	0.0562

Table 4.12 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=26,d2=10)

V_2	Porosity Determined Experimentally	Porosity Calculated by Using Jeschar Equation	Absolute Error	Porosity Calculated by Using Latif Equation	Absolute Error
1	0.4965	0.4322	0.129	0.2417	0.513
0.8923	0.4787	0.4276	0.1067	0.2656	0.445
0.7864	0.4492	0.4156	0.0748	0.2708	0.3972
0.6824	0.4611	0.4007	0.0655	0.2857	0.6902
0.58	0.4316	0.3845	0.1091	0.3007	0.3033
0.479	0.4387	0.3705	0.1554	0.3157	0.2804
0.3803	0.421	0.3615	0.1413	0.3308	0.214
0.2829	0.4259	0.36104	0.1522	0.3457	0.1883
0.1871	0.4377	0.3721	0.149	0.3604	0.1766
0.093	0.4411	0.3962	0.102	0.3748	0.1503

Table 4.13 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=20,d2=10)

V_2	Porosity Determined Experimentally	Porosity Calculated by Using Jeschar Equation	Absolute Error	Porosity Calculated by Using Latif Equation	Absolute Error
1	0.496	0.4206	0.152	0.3096	0.376
0.898	0.466	0.4175	0.104	0.3192	0.315
0.7971	0.465	0.4096	0.119	0.3286	0.293
0.6963	0.464	0.3985	0.141	0.3378	0.272
0.5957	0.429	0.3864	0.099	0.3468	0.192
0.4956	0.424	0.3755	0.114	0.3555	0.161
0.3958	0.428	0.3683	0.139	0.3639	0.149
0.2963	0.427	0.3675	0.139	0.3717	0.129
0.1972	0.426	0.3764	0.116	0.379	0.1103
0.098	0.425	0.3932	0.075	0.3857	0.0925

Table 4.14 Theoretically Porosity as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=26,d2=20).

V_2	Porosity Determined Experimentally	Porosity Calculated by Using Jeschar Equation	Absolute Error	Porosity Calculated by Using Latif Equation	Absolute Error
1	0.488	0.4407	0.0969	0.4648	0.0475
0.894	0.479	0.4394	0.0827	0.4608	0.0182
0.7894	0.479	0.4359	0.0899	0.45505	0.05
0.6862	0.491	0.431	0.1222	0.4494	0.0847
0.5843	0.491	0.4259	0.1326	0.4433	0.0971
0.4838	0.498	0.4216	0.1534	0.4368	0.1229
0.3845	0.486	0.4191	0.138	0.4297	0.1158
0.2865	0.458	0.4195	0.084	0.4221	0.0784
0.1898	0.469	0.4232	0.0976	0.41406	0.1171
0.094	0.497	0.4305	0.1338	0.4055	0.184

The modification of Latif equation under consideration of the porosity of the present work leads to equation 4.7.

$$\varepsilon_f = \left(0.45488 + 0.05466 v_2\right)\left(\frac{d_2}{d_1}\right)^{0.1283-0.04068 v_2} \qquad \text{……………..(4.7)}$$

Table 4.15 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=26,d2=6)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.471	0.4481	0.0486
0.8855	0.4454	0.439	0.0144
0.7746	0.408	0.4314	0.0573
0.6672	0.4176	0.4236	0.0144
0.5631	0.3797	0.4161	0.0958
0.5	0.3893	0.4116	0.0573
0.3642	0.3989	0.4019	0.0075
0.2691	0.3616	0.3953	0.0932
0.1768	0.4099	0.3889	0.0512
0.087	0.4443	0.3828	0.138

Table 4.16 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=20,d2=6)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.471	0.4585	0.0265
0.8919	0.4233	0.4508	0.0649
0.7858	0.4338	0.4433	0.0219
0.6815	0.38	0.4359	0.1471
0.579	0.4083	0.4288	0.0502
0.4783	0.3773	0.4219	0.1182
0.3794	0.364	0.4198	0.1532
0.2821	0.3938	0.4152	0.0543
0.1865	0.4037	0.4086	0.0121
0.0925	0.429	0.4021	0.0627

Table 4.17 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=10,d2=6)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.471	0.4872	0.0344
0.8936	0.4826	0.4806	0.0041
0.7887	0.496	0.474	0.0443
0.6853	0.459	0.4677	0.0189
0.5833	0.455	0.4614	0.014
0.4828	0.4161	0.4553	0.0942
0.3836	0.4328	0.4492	0.0379
0.2857	0.428	0.4441	0.0376
0.1892	0.4408	0.4374	0.0077
0.09396	0.4557	0.4317	0.0527

Table 4.18 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=8,d2=6)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.471	0.4968	0.0548
0.8919	0.483	0.4905	0.0155
0.7858	0.462	0.4842	0.048
0.6815	0.457	0.4781	0.0462
0.579	0.434	0.4721	0.0877
0.4783	0.447	0.4662	0.0429
0.3738	0.442	0.4601	0.0409
0.28209	0.438	0.4547	0.0381
0.1865	0.449	0.4492	0.0004
0.0925	0.462	0.4437	0.0396

Table 4.19 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=26,d2=8)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.4872	0.4595	0.0568
0.894	0.4699	0.452	0.0381
0.7894	0.4416	0.4446	0.0068
0.6862	0.4233	0.4374	0.0333
0.5843	0.3899	0.4304	0.1038
0.4838	0.4036	0.4483	0.111
0.3845	0.378	0.4167	0.1024
0.2866	0.3869	0.4101	0.0599
0.1898	0.4358	0.4036	0.0739
0.0943	0.4402	0.3972	0.0977

Table 4.20 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=20,d2=8)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.4872	0.4702	0.0349
0.9	0.4809	0.4634	0.0364
0.8	0.494	0.4567	0.0755
0.7	0.458	0.4517	0.0137
0.6	0.451	0.4434	0.0168
0.5	0.4129	0.4368	0.0579
0.4	0.4057	0.4302	0.0604
0.3	0.3984	0.4237	0.0635
0.2	0.4133	0.4172	0.0094
0.1	0.442	0.4108	0.0352

Table 4.21 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=10,d2=8)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.4872	0.4997	0.0256
0.9016	0.4881	0.4939	0.0119
0.8028	0.4592	0.4882	0.0631
0.7037	0.46	0.4825	0.0489
0.6043	0.461	0.4767	0.034
0.5044	0.428	0.4709	0.1137
0.4043	0.4295	0.4652	0.0831
0.3037	0.4305	0.4594	0.0671
0.2029	0.4315	0.4536	0.051
0.1016	0.4325	0.4478	0.0353

Table 4.22 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=26,d2=10)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.4965	0.4686	0.0561
0.8923	0.4787	0.4612	0.0366
0.7864	0.4492	0.4541	0.0108
0.6824	0.4611	0.4471	0.0304
0.58	0.4316	0.4402	0.0199
0.479	0.4387	0.4335	0.0118
0.3803	0.421	0.427	0.0143
0.2829	0.4259	0.4207	0.0122
0.1871	0.4377	0.4144	0.0534
0.093	0.4411	0.4083	0.0742

Table 4.23 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=20,d2=10)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.496	0.4795	0.033
0.898	0.466	0.4729	0.015
0.7971	0.465	0.4664	0.003
0.6963	0.464	0.4599	0.009
0.5957	0.429	0.4535	0.056
0.4956	0.424	0.4472	0.056
0.3958	0.428	0.4408	0.0309
0.2963	0.427	0.4346	0.0185
0.1972	0.426	0.4384	0.0063
0.098	0.425	0.4222	0.0058

Table 4.24 Porosity Calculated by Using Modified Latif Equation as Compared to The Experimentally Porosity with Absolute Error for Binary System(d1=26,d2=6)

V2	Porosity Determined Experimentally	Porosity Calculated by Using Modified Latif Equation	Absolute Error
1	0.488	0.4979	0.0245
0.894	0.479	0.4917	0.0272
0.7894	0.479	0.4856	0.0121
0.6862	0.491	0.4796	0.0244
0.5843	0.491	0.4736	0.0362
0.4838	0.498	0.4678	0.0605
0.3845	0.486	0.462	0.0486
0.2865	0.458	0.456	0.0044
0.1898	0.469	0.4507	0.039
0.094	0.497	0.4452	0.104

Table 4.17 to 4.27 Demonstrates the differences in porosity and it's cause will be as follows:-

1- The effect of padding height measurement where as it is difficult to equalize it s surface.
2- The effect of the vessel's diameter, concerning large diameters.
3- Respective irregularity for the shapes of the applied bodes.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

1-The mean pore size will be the property of each packed bed, and will be recognized from other different beds by mean pore size or diameter.

2- The probability of finding pore sizes in any packed bed increased with increasing the diameter of the pore (as explained in theoretical part of research)depending on the equations are taken from Latif .M.N. This proportionality is different for each type of distributions.

3-The percent output of impurities which are passed through the packed bed decreases with the increasing the number of the layers ,and also decrease with the increase in the size of impurities and increasing the number of large spheres in the packed bed leads to an increase in the percent output and this in turn leads to an increase the mean pore diameter (due to number ,length, surface area and volume)and an increase in the number of small or medium spheres leads to reduction in the output of impurities and that in turn leads to a reduction in the mean pore diameter (due to number ,length, surface area and volume).

4-Porosity which is calculated in each kind of distribution decrease with the increasing the number of layers, and also increased with the increasing of mean pore diameter (due to number, length, surface area and volume).

5-For mono size spherical particles system the porosity decreases as the bed diameter increases .and the porosity increases as the diameter of spherical particles increases that leads to say the porosity of mono spherical particles system increases as the ratio (particle diameter /bed diameter) increases. Plot of diameter ratio against porosity was achieved and the advantages of this method are:

- i- It can be consider as a simple method.
- ii- It has the ability of comparison the variation of porosity value with particle size in certain bed.
- iii- An equation can be obtained from it by found a relation ship that describes the curve, (so for any diameter ratio, the value of porosity can be expected with out making any experiments).

6-For binary system mixing particles of different sizes is known to increase the over all porosity, but if the small particles sufficiently small to penetrate the voids associated with the large particles the porosity will decrease, therefore it can be say that the porosity values depends on the particle size and the diameter ratio.

5.2 Recommendation .

1- Developing Latif equation that gives us the relation between the probability and the diameter of the porous, to give accurate results for all types of distribution.

2-Further experiments for pore size should be made on other sizes of fine spheres or impurities to study the properties of the packed bed. Also the number of layers should be increased.

3-Further experiments for pore size should be made for another kind of packed bed which consists of more diameters of sphere and have another number percent.

4-Further experimental work for pore size using various packing, filtering liquids and suspended materials is required to find the usefulness of the theoretical method {studying the effect of the particle shape, the hydraulic gradient, the surface forces, and wall effects}.

5- Using video camera to observe the motion of the impurities when they exit from it, and observe the wall effect, and especially to study the decolmatage or remaining of the impurities.

6-Improvement of the derived empirical equation that calculated porosity can be realized by addition experimental work. Variable new sphere sizes may be attempted for this purpose.

7-Although, further investigation are needed to finding the effects of the surface of particles composing the bed and the surface of the container in the value of porosity.

8-The effect of container wall in the porosity may further more be minimized using a smaller ratio particulate to container diameters.

9-Another types of statistical function may be consider and relating porosity value with its variables, finally comparison between the obtained results with the results of the present work were carried out.

10-Using another packed bed with different diameter and increase the diameter of spheres that composing the bed to increase the porosity.

11-Using another cylinder which contains the packed bed with smaller diameter to increase the porosity.

References

1. A.Marmur, Powder Technology, 44(1985)249.
2. L.H.S.Roblee,R.M.Baird and J.W.Tierney,A.I.Ch.E,4(1958)460.
3. R.F.Fedors, Powder Technology, 23(1979)225.
4. N.Standish and D.E.Dorger, Powder Technology, 22(1979)122.
5. Given on internet " Particle characterization instruments" http://www.quantachrome.com/mercury poromsimetry/pore master GT.htm.
6. W.James , Powder Technology 20(1978)115-120.
7. Given on internet by A.Benoit (predicting unsaturated hydraulic conductivity of coarse un consolidated sediment based on grain size)1992 at. http://www.osti.gov/energy citations /product.bib/io.jsp?osti id=5808958.
8. G.p Androutsopoulos and E.T Woodburn, Powder Technology 33(1982)175-186.
9. Y.Jwang, T.C.WU and C.L chiang,Aiche Journal September 1989 vol 35 No 9.
10. J.Van Brakel ,Powder Technology ,11(1975) 205.
11. I.Garcia –Bengochea Dolch, J.colloid interface sci, 38(1972)234-244.
12. T.S Ramakrishnan and D.T Wasan Powder Technology 48(1986)99-124.
13. L.Paterson V.Hornof and G.Neale Powder Technology, 33(1982)265-268.
14. J.D Bernol and J.Mason ,nature ,188,1960,910 as cited in Ref 54.
15. A.K.Singhal and P.M Dranchuk, Powder Technology, 11(1975)45
16. I.Mahgoub, C.Prost and J.A. Dodds Powder Technology 31(1982)143-151.
17. M.Muskat PH.D (the flow of homogenous fluids through porous media) 1946.
18. S.Habib and S.Muhammad Chemical Engineering Science vol 45, No.1 pp163-182, 1990
19. E. Adrian .Scheidegger (The physics of flow through porous media) 1960.
20. Y.Nakano and J.W. Evans Powder Technology 35(1983)115-118.
21. R.Francoise ,R. Jean and S.Kenneth (the adsorption by powders and porous solids), 1999
22. G.P .Androutsopoulos and T.H.J. Linardos, Powder Technology, 47(1986)9-15.
23. P.Legoff, D.Leclere and J.Dodds, Powder Technology, 42(1985)47-53.
24. M.Suzuki and T.Oshima, Powder Technology, 44(1985) 213-218.
25. J.Rodriguez and C.H Allibert and J.M.Chaix, Powder Technology 47(1986)25-33.
26. Given on internet (kissing number) http:// math world .wolfram.com/kissing number.htm.
27. W.A.Gray, the packing of solid particles, Chapman and Hall, London, 1968.

28. K.J.Ives, The scientific basis of filtration, London, 1975.
29. Given on internet (Filtration basis)
http:// www.techno-filt .com/basic filtration .htm.
30. Given on internet (Water filtration guide)
http:// www.blank.005.tripod.com/comping/equipment/guide filter.htm1.
31. Given on internet (principles of filtration)
http:// www.pall.com/17761-4740.
32. Given on internet (pore size meter PSM 160/165)
http:// www.topas-gmbh.de/poro.htm.
33. J.Beck, sums of distances between points on a sphere, math 31(1984)33-41.
34. Given on internet by I. Peterson (Cracking Kepler's sphere-packing problem) at August 15, 1998
35. Given on internet by Dr.S.J.Heyes (Structures of simple inorganic solids) 2000.at
http:// www.chem.ox.ac.uk/ic/heyes/structure of solids/ecture 1/lec 1.htm 1.
36. T.Stovall, F.Delarrard and M.Buil Powder technology 48(1986)1-12.
37. Given on internet (Wikipedia information about sphere packing)
http:// www.answers.com/topic/sphere packing.
38. Given on internet by Eric W.Weisstein (sphere packing) 1999 at.
http://math world.wlfram.com/sphere packing .htm.
39. D.Scott , Nature, 188, 1960,908.
40. K.Ridge way and K.J Tarbuck ,British ,Chemical Engineering ,12,1967,384.
41. Given on internet by R. Angle (packed bed calculator. porous media permeameter) 2001.at
http:// www.imnoeng.com/ground water/packed bed .htm.
42. Given on internet (Using computational fluid dynamics to simulate the flow through novel support structures for liquid chromatography) 2004 at.
http://www.vub.ac.be/chis/nico.htm.
43. Given on internet by Gondkar,H.Manud ,Amritkar,Paia,Lali(Effect of adsorbent porosity on performance of expanded bed chromatography of proteins) 2001 at.
http://www.ncbi.nlm.nih.gov/entrez/query Fcgi?cmd=Retrieve & db=pub med&list uids=11386874& dopt =abstract.
44. Given on internet byA. Jey (performance of anaerobic packed bed system with different media characterististics) 1996 at.
http://www.iwapon /ine.com/wst/03405/wst 034050453.htm
45.S.J Gregg and K.S.W. Sing ,.adsorption, surface area and porosity 2nd Ed, academic press New York, 1982.

46. Given on internet by Y.B.P Kwan, D.J. Stephenson and J.R. Alcock (The dependence of pore size distribution on porosity in hot iso statically pressed porous alumina) 2001 at.
http:// www.spring er link.com/app/home/contribution.asp?wasp=off 36f1 daqa 04 d7eae 5dc3ff 35fc 0003 & referrer=parent & back to.
47. S.Diamond and W.L.Dolch, J.Colloide interface sci, 38(1972)234-244.
48. B.Gerald and G.David Chemical engineering science, vol.4, No11 p2079-2085.
49. M.Surendra, ph.D.Thesis, Purdue univ., W.Lafayette, Ind, 1980, 304pp.
50. M.Kaneuji, D.N.Winslow and W.L. Dolch.Cem Concr .Res (May 1980).
51. M.N.Latif Ph.D.Thesis,Beitrag Zur ModellierungVonAuch Wemmschichten ,Dresdem,Germany 1981.
52. N.Fawaz , M.Sc Thesis, Pore size in packed bed consisting of three sizes of spheres, Saddam University, 1997.
53. H.Y. AL-obaidi., M.Sc.Thesis,Pore size in packed of mixed spheres ,Saddam University, 1994.
54. M.Omar , M.Sc Thesis, Pore size in binary mixture, Saddam University, 1999.
55. Given on internet (Porosity)
http:// www.glossary .oil field.slb.com/display.cfm?term=porosity.
56. H.J.Fraser and L.C.Garton, J.Geology, 43(1935)785 .
57. J.P.Hurbisck,D.M.Lectere,P.Legoff,Ind.and Eng.Chem.,62(1970)
58. W.O.Swith, Phs.Rev, 24(1929)1271 .
59. Y.L.HE, S.Z.Qin, C.J.Lim and J.R Grace, the Canadian Journal of Chemical Engineering, 72(1994)561 .
60. L.H.S.Roblee, R.M.Baird and J.W.Tierney, A.I.Ch.E, 4(1958)460
61. R.Fbenenti and C.B.Brosilow, A.I.Ch.E., 8(1962)359.
62. D.P.Haughey and G.S.G Beverige, Chem.Eng.Sci, 21(1966)905
63. K.Ridgway and K.J.Tarbuck, Chem.Eng.Sci, 23(1968)1147
65. M.H. Venneti,Govindarao and G.F.Froment,Chem.Eng.Sci.,41(1986)533.
64. D.Vortmeyer and J.Schuster, Chem.Eng.Sci, 38(1983)1691
66. J.Kubie, Chem.Eng.Sci, 43(1988) 1403 .
67. N.Ouchiyama and T.Tanka,Ind.Eng.Chem,Fund ,25(1986)125 .
68. N.Standish and A.B.Yu, Powder Technology, 49(1987)249 .
69. N.S.Rasheed, M.Sc.Thesis, Porosity determination of multi-component system using discontinuous size distribution, Saddam University, 1994.
70. F.R.Al.Azzawi, M.SC.Thesis, Influence of the particle size distribution on the porosity of glass spheres,Saddam University,1996.
71. A.A.Al.Ramahi, M.Sc.Thesis, Porosity determination of multicomponent system, Saddam University, 1997.
72. C.C.Furnas, Ind.Eng.Chem, 23(1993)1052 .

APPENDIX [A]

SAMPLE OF CALCULATIONS

A.1.1 For pore size calculation.

d_1=6, d_2=8, d_3=10, d_4=20, d_5=26
Example N_1=0.1, N_2=0.1, N_3=0.2, N_4=0.54, N_5=0.06

For the case of three different sizes of spheres:-

Example if we take d_1, d_2, d_3 (d_k=6,d_m=8,d_g=10)

$$d_{ciii} = \frac{k_4 - \left(k_4^2 - 4k_5\right)^{1/2}}{2} \times d_g \quad \text{...........} \ (2.3)$$

Where

$$k_1 = \left[\frac{(am+1)}{(am-1)}\right]^2$$

$$am = \frac{dm}{dg} \qquad \rightarrow \qquad am=0.8$$

k_1=262.44

$$k_2 = \frac{4am}{(am+1)}$$

k_2=1.7777

$$k_3 = \left(a_k^2 + a_k k_2\right)^{1/2} - a_k$$

$$a_k = \frac{dk}{dg} \quad (\leq) \rightarrow a_k=0.6$$

k_3=0.5944

$k_4 = (k_2 + 2k_3) \times k_1$

k_4=778.544

$k_5 = k_3^2 \times k_1$

k_5=92.7323

dc_{iii}=1.19128 mm

For the case of two large diameters and one small diameter:-
Example if we take d_1, d_2, d_3 (d_k=6,d_m=8,d_g=8)

$$d_{ciii} = \frac{\left[\left(2a_k + a_k^2\right)^{1/2} - a_k\right]^2}{2 + 2\left[\left(2a_k + a_k^2\right)^{1/2} - a_k\right]} \times d_g \quad \text{………..} \ (2.4.a)$$

dc_{ii}=1.116843 mm
For the case of two small diameters and one large diameter:-
Example if we take d_1, d_2, d_3 (d_k=6,d_m=6,d_g=8)

$$d_{cii} = \frac{\left[\left(2/a_k + a_k^{-2}\right)^{1/2} - a_k^{-1}\right]^2}{2 + 2\left[\left(2/a_k + a_k^{-2}\right)^{1/2} - a_k^{-1}\right]} \times d_k \quad \text{………} (2.4.b)$$

dc_{ii}=1.014832 mm.

For the case of three equal diameters:-
Example if we take d_1, d_1, d_1 (d_k=6,d_m=6,d_g=6)

$d_{ci} = 0.155 \times d_g$ …… (2.5)
dc_i=0.924 mm.

A.1.2 For probability calculation.

d_1=6, d_2=8, d_3=10, d_4=20, d_5=26
N_1=0.1, N_2=0.1, N_3=0.2, N_4=0.54, N_5=0.06

i- Calculate probability due to length.

$$L = (d_1 \times N_1) + (d_2 \times N_2) + (d_3 \times N_3) + (d_4 \times N_4) + (d_5 \times N_5)$$

L=15.76

For d_k=6,d_m=8,d_g=10.

$$L_k = (d_k \times N_k)/L$$

L_k=0.03807

$$L_m = (d_m \times N_m)/L$$

L_m=0.05076

$$L_g = (d_g \times N_g)/L$$

L_g=0.1269
Where N: number percent.

$$P_i = \frac{3!}{n_g!\,n_m!\,n_k!} Pr_{dg}^{ng} \times Pr_{dm}^{nm} \times Pr_{dk}^{nk} \quad \ldots\ldots\ (2.6)$$

Where $r_g + r_m + r_k = 3$
P_i=0.00147

ii-Calculate the probability due to area.

$$A=\left(d_1^2\times N_1\right)+\left(d_2^2\times N_2\right)+\left(d_3^2\times N_3\right)+\left(d_4^2\times N_4\right)+\left(d_5^2\times N_5\right)$$

A=286.56

$$A_k=\left(d_k^2\times N_k\right)/A$$

A_k=0.01256

$$A_m=\left(d_m^2\times N_m\right)/A$$

A_m=0.02233

$$A_g=\left(d_g^2\times N_g\right)/A$$

A_g=0.069793

According to eq 2-6 P_i=0.000117446

iii-Calculate the probability due to volume.

$$V=\left(d_1^3\times N_1\right)+\left(d_2^3\times N_2\right)+\left(d_3^3\times N_3\right)+\left(d_4^3\times N_4\right)+\left(d_5^3\times N_5\right)$$

V=5647.36

$$V_k=\left(d_k^3\times N_k\right)/V$$

V_k=0.00382

$$V_m=\left(d_m^3\times N_m\right)/V$$

V_m=0.009066

$V_g = \left(d_g^3 \times N_g\right)/V$

V_g =0.0354

P_i =7.355E-06

A.1.3 Calculation of the mean pore diameter.

$$d_{cm} = \sum_{i=1}^{n} p_i d_{ci} \;\ldots\ldots\; (2.7)$$

To determine the mean pore diameter due to number

$$d_{cm}n = \sum_{i=1}^{n} p_{rn} d_{ci} \quad \longrightarrow \quad d_{cm}n = 2.2045 \text{ mm.}$$

To determine the mean pore diameter due to length

$$d_{cm}l = \sum_{i=1}^{n} p_{rl} d_{ci} \quad \longrightarrow \quad d_{cm}l = 2.683 \text{ mm.}$$

To determine the mean pore diameter due to area

$$d_{cm}a = \sum_{i=1}^{n} p_{ra} d_{ci} \quad \longrightarrow \quad d_{cm}a = 2.999 \text{ mm.}$$

To determine the mean pore diameter due to volume

$$d_{cm}v = \sum_{i=1}^{n} p_{rv} d_{ci} \quad \longrightarrow \quad d_{cm}v = 3.204 \text{ mm.}$$

A.2 For Porosity calculation.

1. For mono system.

a) Furnas equation.

$$\varepsilon = 0.375 + 0.34\frac{d}{D} \ldots\ldots \text{(2.9)}$$

Where:

If we take sphere of diameter 6mm.

In cylinder of diameter 12.9 cm.

$$\frac{d}{D} = 0.0465$$

$\varepsilon = 0.375 + 0.34 \times 0.0465 = 0.3908$

in cylinder of diameter 6.4 cm.

$$\frac{d}{D} = 0.09375$$

$\varepsilon = 0.375 + 0.34 \times 0.09375 = 0.4069$

Further values see table (B.26).

b) Calculate the porosity experimentally from eq $\varepsilon = \frac{V}{V_T}$.

$$V = V_T - V_p$$

For cylinder of D=12.9 cm.

If we take spheres d=6mm, number of sphere taken from table (3.3) N=1049. The height measured is 1.5cm.Further values see table (C.13)

$$V_T = \frac{\pi}{4} d^2 . L$$

V_T =195.94777cm³

$$V_P = \frac{\pi}{6} d^3 . N$$

V=118.5786 cm³

Vp=195.9477-118.5786=77.368 cm³

ε =0.3948.

Further values see table (C.14)

2. For binary system

A.Jeschar equation.

If we take d_1= 26,d_2=6 mm.

$$\varepsilon = \frac{1}{1 - x\dfrac{\varepsilon_o - 1}{\varepsilon_o . v_2}} \quad \ldots\ldots\ldots\ldots (2.10)$$

$$\varepsilon_o = \frac{\varepsilon \ at \ d_1 + \varepsilon \ at \ d_2}{2}$$

ε_o=0.4235

Where ε from table (C.14)

To calculate the fractional volumes of sphere take basis 300 g:

$$v_2 = \frac{\left(\dfrac{W_2}{\rho_2}\right)}{\left(\dfrac{W_2}{\rho_2}\right) + \left(\dfrac{W_1}{\rho_1}\right)} \ldots\ldots.. (A.1)$$

Where W_2 presented in tables (B.27) to (B.36)

ρ_1 & ρ_2 From table (3.1)

If we take 10% d_2, 90% d_1.

$$v_2 = \frac{\left(\frac{30}{2.71479}\right)}{\left(\frac{30}{2.71479}\right)+\left(\frac{270}{2.332785}\right)} = 0.087155$$

Further values see from table (B.27) to (B.36).

$$X = \frac{1}{1+\frac{(1-v_2)}{v_2}\left(\frac{d_2}{d_1}\right)^{0.6\sin \pi v_2}}$$

X=0.10798

ε=0.3722

Further values see from table (B.27) to (B.36).

B . Latif equation.

If we take d_1= 26,d_2=6 mm.

$v_2 = 0.087155$

$$\varepsilon = (0.3994 + 0.196 v_2)\left(\frac{d_2}{d_1}\right)^{0.0283+0.9152 v_2} \quad \text{..................(2.11)}$$

$$\varepsilon = (0.3994 + 0.196 \times 0.087155)\left(\frac{6}{26}\right)^{0.0283+0.9152\times 0.087155} = 0.355$$

APPENDIX [B]

B.1Theortical Resluts(Pore Size).

Equation of the theoretical work is applied using a suitable computer programs, tables from B.2 to B.12 shows the results obtained by the computer programs that have been written for calculating the pore size distribution due to surface area ,number ,volume ,and calculating the mean pore diameter for different values of particle diameter.

Table B.1 Arrangement of Particles to Determine the Diameter of The pore.

No. of Small Spheres	No. of Medium Spheres	No. of Large Spheres	Arrangement	dc(mm)	Equation Used
3	0	0	d_1,d_1,d_1	0.93	2-5
2	0	1	d_1,d_1,d_2	1.0148	2-4.b
2	0	1	d_1,d_1,d_3	1.0779	2-4.b
1	0	2	d_1,d_2,d_2	1.117	2-4.a
1	1	1	d_1,d_2, d_3	1.1913	2-3
0	3	0	d_2,d_2,d_2	1.24	2-5
2	0	1	d_1,d_1,d_4	1.247	2-4.b
1	0	2	d_1,d_3,d_3	1.277	2-4.a
2	0	1	d_1,d_1,d_5	1.291	2-4.b
2	0	1	d_2,d_2, d_3	1.328	2-4.b
1	1	1	d_1,d_2, d_4	1.389	2-3
1	0	2	d_2,d_3,d_3	1.43	2-4.a
1	1	1	d_1,d_2, d_5	1.44	2-3
1	1	1	d_1,d_3, d_4	1.517	2-3
0	3	0	d_3,d_3,d_3	1.55	2-5
1	1	1	d_1,d_3, d_5	1.57	2-3
2	0	1	d_2,d_2, d_4	1.581	2-4.b
2	0	2	d_2,d_2, d_5	1.6496	2-4.b
1	1	1	d_2,d_3, d_4	1.716	2-3
1	1	1	d_2,d_3, d_5	1.789	2-3

1	0	2	d_1, d_4, d_4	1.861	2-4.a
2	0	1	d_3, d_3, d_4	1.89	2-4.b
1	1	1	d_1, d_4, d_5	1.916	2-3
2	0	1	d_3, d_3, d_5	1.9822	2-4.b
1	0	2	d_1, d_5, d_5	2.0715	2-4.a
1	0	2	d_2, d_4, d_4	2.155	2-4.a
1	1	1	d_2, d_4, d_5	2.28	2-3
1	0	2	d_3, d_4, d_4	2.393	2-4.a
1	0	2	d_2, d_5, d_5	2.424	2-4.a
1	1	1	d_3, d_4, d_5	2.532	2-3
1	0	2	d_3, d_5, d_5	2.714	2-4.a
0	3	0	d_4, d_4, d_4	3.1	2-5
2	0	1	d_4, d_4, d_5	3.417	2-4.b
1	0	2	d_4, d_5, d_5	3.699	2-4.a
0	0	3	d_5, d_5, d_5	4.03	2-5

Table B.2 Results Obtained from Computer Program for:
$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$

N_1=0.1	N_2=0.1	N_3=0.2	N_4=0.54	N_5=0.06
L_1=0.038	L_2=0.05076	L_3=0.1269	L_4=0.6853	L_5=0.0989
A_1=0.0126	A_2=0.0223	A_3=0.0698	A_4=0.7538	A_5=0.1415
V_1=0.00382	V_2=0.00907	V_3=0.0354	V_4=0.7649	V_5=0.1867

Diameter of the pores (dc)	**Probability Due to Number(P_{rn})**	**Probability Due to Length(P_{rl})**	**Probability Due to Area (P_{ra})**	**Probability Due to Volume(P_{rv})**
0.93	0.001	5.52E-05	1.9814E-6	5.595E-8
1.0148	0.004	0.000276	1.2549E-5	4.539E-7
1.0779	0.01	0.000828	4.5578E-5	2.008E-6
1.117	0.013	0.001122	6.437E-5	2.951E-6
1.1913	0.025	0.002593	1.818E-4	1.0319E-5

1.24	0.026	0.002724	1.9294E-4	1.1064E-5
1.247	0.042	0.005704	5.4967E-4	4.4639E-5
1.277	0.0542	0.007543	7.3319E-4	5.9028E-5
1.291	0.056	0.007973	8.0018E-4	6.7224E-5
1.328	0.062	0.008954	9.046E-4	7.5955E-5
1.389	0.094	0.016899	2.1729E-3	2.351E-4
1.43	0.106	0.019352	2.499E-3	2.692E-4
1.44	0.11	0.020499	2.7374E-3	3.0806E-4
1.517	0.175	0.040363	6.7017E-3	9.2966E-4
1.55	0.183	0.042406	7.0416E-3	9.7406E-4
1.57	0.19	0.045276	7.7858E-3	1.1258E-3
1.581	0.206	0.050573	8.9134E-3	1.3144E-3
1.6496	0.208	0.051338	9.125E-3	1.3605E-3
1.716	0.273	0.077822	1.6173E-2	2.8338E-3
1.789	0.28	0.081648	1.7496E-2	3.1935E-3
1.861	0.367	0.13528	3.8904E-2	9.9077E-3
1.89	0.432	0.168386	4.9918E-2	1.2785E-2
1.916	0.452	0.18388	5.7956E-2	1.6063E-2
1.9822	0.458	0.188661	6.0023E-2	1.677E-2
2.0715	0.46	0.18978	6.0778E-2	0.0172
2.155	0.547	0.26129	9.8838E-2	3.308E-2
2.28	0.567	0.281948	0.1131	4.0848E-2
2.393	0.742	0.460723	0.232	0.103
2.424	0.743	0.462215	0.2334	0.10395
2.532	0.782	0.513859	0.2781	0.1343
2.714	0.784	0.517589	0.2823	0.138
3.1	0.941	0.839388	0.7105	0.5855
3.417	0.994	0.978829	0.9517	0.91327
3.699	0.9998	0.99897	0.99699	0.9933
4.03	1	1	1	1

Table B.3 Results Obtained from Computer Program for:
$d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26$

N_1=0.15	N_2=0.15	N_3=0.2	N_4=0.44	N_5=0.06
L_1=0.0622	L_2=0.08299	L_3=0.1383	L_4=0.6086	L_5=0.1079
A_1=0.02147	A_2=0.03816	A_3=0.0795	A_4=0.6996	A_5=0.1612
V_1=0.00663	V_2=0.0157	V_3=0.04095	V_4=0.7208	V_5=0.2159

Diameter of the pores (dc)	**Probability Due to Number(P_{rn})**	**Probability Due to Length(P_{rl})**	**Probability Due to Area (P_{ra})**	**Probability Due to Volume(P_{rv})**
0.93	3.375E-04	2.41E-04	9.891E-6	2.92E-07
1.0148	0.0135	0.001205	6.2642E-5	2.37E-06
1.0779	0.027	0.002809	1.7254E-4	7.77E-06
1.117	0.0371	0.004095	2.663E-4	1.27E-05
1.1913	0.0641	0.00837	6.5705E-4	3.83E-05
1.24	0.0675	0.00894	7.1262E-4	4.22E-05
1.247	0.0972	0.01602	1.6798E-3	1.37E-04
1.277	0.115	0.01957	2.0868E-3	1.71E-04
1.291	0.119	0.02083	3.7608E-3	1.99E-04
1.328	0.133	0.02368	4.108E-3	2.3 E-04
1.389	0.192	0.0425	7.5467E-3	6.81 E-04
1.43	0.2101	0.04728	8.2703E-3	7.6 E-04
1.44	0.218	0.05062	9.0627E-3	8.95 E-04
1.517	0.297	0.08198	1.6226E-2	0.00207
1.55	0.305	0.0846	1.6729E-2	0.002138
1.57	0.316	0.09017	1.838E-2	0.00249
1.581	0.346	0.1027	1.9084E-2	0.003025
1.6496	0.35	0.10497	1.979E-2	0.003185
1.716	0.429	0.1468	3.252E-2	0.00597
1.789	0.44	0.15419	3.5458E-2	0.006804
1.861	0.527	0.2233	6.698E-2	0.01714
1.89	0.579	0.2581	8.0246E-2	0.02077
1.916	0.604	0.2826	9.4774E-2	0.02696

1.9822	0.611	0.2888	9.783E-2	0.02805
2.0715	0.612	0.29097	9.951E-2	0.02898
2.155	0.699	0.3832	0.156	0.0535
2.28	0.723	0.41585	0.1814	0.0682
2.393	0.839	0.5692	0.2981	0.13199
2.424	0.841	0.572	0.3011	0.13418
2.532	0.873	0.6264	0.3549	0.1724
2.714	0.875	0.6313	0.36109	0.1781
3.1	0.9601	0.85665	0.7036	0.5526
3.417	0.995	0.9765	0.9403	0.889
3.699	0.9997	0.9978	0.9949	0.9898
4.03	1	1	1	1

Table B.4 Results Obtained from Computer Program for:
$d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26$

N_1=0.2	N_2=0.2	N_3=0.15	N_4=0.43	N_5=0.02
L_1=0.0894	L_2=0.119	L_3=0.1118	L_4=0.6408	L_5=0.0387
A_1=0.0327	A_2=0.05804	A_3=0.06802	A_4=0.7799	A_5=0.0613
V_1=0.01057	V_2=0.02505	V_3=0.0367	V_4=0.8417	V_5=0.086

Diameter of the pores (dc)	Probability Due to Number(P_{rn})	Probability Due to Length(P_{rl})	Probability Due to Area (P_{ra})	Probability Due to Volume(P_{rv})
0.93	0.008	7.15E-04	3.4806E-5	1.1806E-6
1.0148	0.032	0.003573	2.2043E-4	9.575E-6
1.0779	0.05	0.006253	4.3797E-4	2.187E-5
1.117	0.074	0.010063	7.6797E-4	4.177E-5
1.1913	0.11	0.01721	1.541E-3	1.0007E-4
1.24	0.118	0.018903	1.737E-3	1.158E-4
1.247	0.169	0.034268	4.231E-3	3.978E-4
1.277	0.183	0.037618	4.684E-3	4.4054E-4
1.291	0.185	0.038548	4.8804E-3	4.694E-4
1.328	0.203	0.043312	5.2671E-3	4.9851E-4
1.389	0.307	0.084284	1.4135E-2	1.8355E-3

1.43	0.32	0.088751	1.4941E-2	1.9367E-3
1.44	0.325	0.091229	1.5638E-2	2.073E-3
1.517	0.402	0.129647	2.603E-2	4.0321E-3
1.55	0.406	0.131043	2.6345E-2	4.082E-3
1.57	0.409	0.133366	2.7162E-2	4.2817E-3
1.581	0.461	0.160681	3.5045E-2	5.8661E-3
1.6496	0.463	0.162333	3.5664E-2	6.028E-3
1.716	0.541	0.213557	5.41393E-2	1.067E-2
1.789	0.544	0.216655	5.5592E-2	1.1145E-2
1.861	0.655	0.326784	0.1152	3.3606E-2
1.89	0.684	0.3508	0.12599	3.7007E-2
1.916	0.695	0.364119	0.13536	4.1597E-2
1.9822	0.696	0.365571	0.1362	4.194E-2
2.0715	0.696	0.365974	0.13658	4.2179E-2
2.155	0.807	0.512814	0.2425	9.541E-2
2.28	0.817	0.530573	0.25915	0.1063
2.393	0.9007	0.668259	0.3833	0.1843
2.424	0.901	0.668796	0.3839	0.1848
2.532	0.909	0.685448	0.40343	0.20078
2.714	0.909	0.685952	0.4042	0.20159
3.1	0.988	0.94908	0.8786	0.79782
3.417	0.9994	0.996815	0.9904	0.9806
3.699	0.999992	0.999702	0.9993	0.99926
4.03	1	1	1	1

Table B.5 Results Obtained from Computer Program for:
$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$N_1 = 0.25$	$N_2 = 0.2$	$N_3 = 0.182$	$N_4 = 0.348$	$N_5 = 0.02$
$L_1 = 0.1209$	$L_2 = 0.129$	$L_3 = 0.147$	$L_4 = 0.561$	$L_5 = 0.0419$
$A_1 = 0.0467$	$A_2 = 0.0664$	$A_3 = 0.0944$	$A_4 = 0.7229$	$A_5 = 0.0702$
$V_1 = 0.0155$	$V_2 = 0.0295$	$V_3 = 0.0524$	$V_4 = 0.8014$	$V_5 = 0.1012$

Diameter of the pores (dc)	Probability Due to Number(P_{rn})	Probability Due to Length(P_{rl})	Probability Due to Area (P_{ra})	Probability Due to Volume(P_{rv})
0.93	0.0156	0.00177	1.02E-04	3.76E-06
1.0148	0.0531	0.0074	5.36 E-04	2.51E-05
1.0779	0.0872	0.0139	0.00115	6.31E-05
1.117	0.1172	0.0199	0.00177	1.04E-04
1.1913	0.1718	0.0337	0.00353	2.48 E-04
1.24	0.1798	0.0358	0.00382	2.73 E-04
1.247	0.2451	0.06045	0.00855	8.54 E-04
1.277	0.2699	0.06827	0.009795	9.82 E-04
1.291	0.2737	0.0701	0.01025	0.00106
1.328	0.2955	0.0774	0.0115	0.00119
1.389	0.3999	0.13	0.0249	0.00339
1.43	0.4198	0.1383	0.0267	0.00364
1.44	0.4258	0.14227	0.02802	0.0039
1.517	0.5208	0.2021	0.0471	0.0078
1.55	0.5268	0.2052	0.04797	0.00798
1.57	0.5323	0.2097	0.04983	0.00847
1.581	0.5741	0.2377	0.05938	0.0106
1.6496	0.5764	0.23981	0.0603	0.0108
1.716	0.6524	0.3036	0.0875	0.0182
1.789	0.6568	0.3084	0.0901	0.01918
1.861	0.7476	0.42268	0.1632	0.0491
1.89	0.7822	0.45896	0.1825	0.0557
1.916	0.7927	0.476	0.1967	0.06329
1.9822	0.7947	0.4787	0.1986	0.0641
2.0715	0.7949	0.4794	0.1993	0.0646
2.155	0.8676	0.6013	0.3032	0.1214
2.28	0.8759	0.6195	0.3234	0.1357
2.393	0.9421	0.75825	0.4712	0.2367
2.424	0.9423	0.7589	0.4721	0.2376
2.532	0.9499	0.7796	0.50086	0.263
2.714	0.9502	0.7804	0.50225	0.2647
3.1	0.9923	0.95724	0.879	0.7794
3.417	0.9996	0.997	0.98896	0.9743

3.699	0.999992	0.9998	0.9996	0.9989
4.03	1	1	1	1

Table B.6 Results Obtained from Computer Program for:
$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

N_1 = 0.4	N_2 = 0.2	N_3 = 0.15	N_4 = 0.23	N_5 = 0.02
L_1 = 0.226	L_2 = 0.1506	L_3 = 0.141	L_4 = 0.433	L_5 =0.0489
A_1 =0.0975	A_2 =0.0866	A_3 =0.1015	A_4 =0.6228	A_5 =0.0915
V_1 =0.0341	V_2 =0.0405	V_3 =0.0593	V_4 =0.727	V_5 =0.139

Diameter of the pores (dc)	**Probability Due to Number(P_{rn})**	**Probability Due to Length(P_{rl})**	**Probability Due to Area (P_{ra})**	**Probability Due to Volume(P_{rv})**
0.93	0.064	0.0115	9.26E-04	3.98E-05
1.0148	0.16	0.0346	0.003396	1.81E-04
1.0779	0.232	0.0563	0.00629	3.89 E-04
1.117	0.28	0.07165	0.00849	5.56 E-04
1.1913	0.352	0.1005	0.01363	0.00105
1.24	0.36	0.1039	0.0143	0.0011
1.247	0.4704	0.1703	0.032	0.00366
1.277	0.4974	0.1838	0.03505	0.00402
1.291	0.507	0.1913	0.03766	0.0045
1.328	0.525	0.2009	0.03995	0.00479
1.389	0.6354	0.28936	0.07151	0.0108
1.43	0.6489	0.2984	0.07419	0.01125
1.44	0.6585	0.3083	0.07883	0.0124
1.517	0.7413	0.3913	0.11582	0.0212
1.55	0.7447	0.39407	0.11687	0.02144
1.57	0.7519	0.40338	0.1223	0.02313
1.581	0.7795	0.43288	0.13633	0.0267
1.6496	0.7819	0.43619	0.13839	0.0274
1.716	0.8233	0.4915	0.1713	0.03785
1.789	0.8269	0.4977	0.1761	0.03985

1.861	0.8903	0.62489	0.2895	0.09402
1.89	0.9059	0.6508	0.30879	0.1017
1.916	0.9169	0.6794	0.3421	0.1224
1.9822	0.9183	0.6823	0.34496	0.1238
2.0715	0.9187	0.6839	0.3474	0.12582
2.155	0.9505	0.76866	0.44823	0.19002
2.28	0.95601	0.78769	0.47786	0.2145
2.393	0.97982	0.8672	0.596	0.3086
2.424	0.98005	0.8683	0.5982	0.3109
2.532	0.98419	0.88609	0.6329	0.3469
2.714	0.9844	0.88709	0.6355	0.3503
3.1	0.9965	0.9684	0.877	0.73481
3.417	0.99971	0.9957	0.9835	0.9552
3.699	0.999992	0.99878	0.99915	0.9973
4.03	1	1	1	1

Table B.7 Results Obtained from Computer Program for:
$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$

$N_1 = 0.05$	$N_2 = 0.06$	$N_3 = 0.09$	$N_4 = 0.7$	$N_5 = 0.1$
$L_1 = 0.0164$	$L_2 = 0.0263$	$L_3 = 0.0492$	$L_4 = 0.766$	$L_5 = 0.142$
$A_1 = 0.00497$	$A_2 = 0.0106$	$A_3 = 0.0248$	$A_4 = 0.773$	$A_5 = 0.1866$
$V_1 = 0.00144$	$V_2 = 0.0041$	$V_3 = 0.012$	$V_4 = 0.748$	$V_5 = 0.235$

Diameter of the pores (dc)	**Probability Due to Number(P_{rn})**	**Probability Due to Length(P_{rl})**	**Probability Due to Area (P_{ra})**	**Probability Due to Volume(P_{rv})**
0.93	1.25E-04	4.42E-06	1.23E-07	3E-09
1.0148	5.75E-04	2.56E-05	9.08E-07	2.86E-08
1.0779	1.25E-03	6.54E-05	2.75E-06	1.03E-07
1.117	1.79E-03	9.94E-05	4.42E-06	1.76E-07
1.1913	3.41E-03	2.27E-04	1.23E-05	6.02E-07
1.24	3.626E-03	2.45 E-04	1.35E-05	6.71E-07
1.247	8.876E-03	8.64 E-04	7.07E-05	5.33E-06
1.277	0.0101	9.83 E-04	7.99E-05	5.96E-06

1.291	0.0108	1.098E-03	9.37E-05	7.42E-06
1.328	0.0181	1.2 E-03	0.000102	8.03E-06
1.389	0.02441	3.18 E-03	0.000346	3.46E-05
1.43	0.02587	3.371 E-03	0.000366	3.63E-05
1.44	0.02767	7.38 E-03	0.000425	4.46E-05
1.517	0.04657	7.451 E-03	0.000998	0.000122
1.55	0.0473	7.571 E-03	0.001013	0.000124
1.57	0.05	8.26 E-03	0.001151	0.000148
1.581	0.0576	9.844 E-03	0.001412	0.000186
1.6496	0.0586	0.01014	0.001475	0.000198
1.716	0.0813	0.0161	0.002696	0.000419
1.789	0.0846	0.01718	0.002991	0.000488
1.861	0.1581	0.0461	0.011897	0.002906
1.89	0.1751	0.0516	0.013329	0.003229
1.916	0.1961	0.0624	0.017629	0.004748
1.9822	0.1985	0.0634	0.017974	0.004849
2.0715	0.2	0.0644	0.018493	0.005087
2.155	0.2882	0.1106	0.037493	0.011964
2.28	0.3134	0.1278	0.046666	0.01628
2.393	0.4457	0.21438	0.091198	0.036406
2.424	0.4475	0.21598	0.092306	0.037084
2.532	0.4853	0.24816	0.113807	0.049717
2.714	0.488	0.25114	0.116402	0.0517
3.1	0.831	0.70035	0.5782	0.469706
3.417	0.978	0.95062	0.91268	0.8633
3.699	0.999	0.9971	0.9934	0.98684
4.03	1	1	1	1

Table B.8 Results Obtained from Computer Program for:
$d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26$

$N_1 = 0.5$	$N_2 = 0.132$	$N_3 = 0.118$	$N_4 = 0.23$	$N_5 = 0.02$
$L_1 = 0.289$	$L_2 = 0.1019$	$L_3 = 0.114$	$L_4 = 0.444$	$L_5 = 0.05$
$A_1 = 0.125$	$A_2 = 0.0588$	$A_3 = 0.082$	$A_4 = 0.6399$	$A_5 = 0.094$
$V_1 = 0.0434$	$V_2 = 0.0272$	$V_3 = 0.0475$	$V_4 = 0.74$	$V_5 = 0.1415$

Diameter of the pores (dc)	Probability Due to Number(P_{rn})	Probability Due to Length(P_{rl})	Probability Due to Area (P_{ra})	Probability Due to Volume(P_{rv})
0.93	0.125	0.0243	1.96 E-03	8.21E-05
1.0148	0.224	0.04998	4.73 E-03	2.36E-04
1.0779	0.3125	0.07866	8.59 E-03	5.05 E-04
1.117	0.3386	0.08769	9.88 E-03	6.02 E-04
1.1913	0.3854	0.1079	0.0135	9.38 E-04
1.24	0.38766	0.1089	0.01371	9.58 E-04
1.247	0.56016	0.2208	0.04379	5.153E-03
1.277	0.58105	0.232	0.0463	5.447 E-03
1.291	0.59605	0.2447	0.0507	6.249 E-03
1.328	0.6022	0.2482	0.0516	6.354 E-03
1.389	0.69329	0.327	0.0798	0.0116
1.43	0.6988	0.3309	0.08103	0.0118
1.44	0.70673	0.3398	0.0852	0.0128
1.517	0.78815	0.4278	0.1246	0.0219
1.55	0.7898	0.4292	0.1252	0.0221
1.57	0.7969	0.4392	0.1309	0.0238
1.581	0.8089	0.453	0.1376	0.0255
1.6496	0.8099	0.4546	0.1386	0.02577
1.716	0.8314	0.4856	0.1571	0.0315
1.789	0.8333	0.489	0.1598	0.0326
1.861	0.9126	0.6605	0.3136	0.10407
1.89	0.9223	0.6778	0.3265	0.1091
1.916	0.936	0.7166	0.3717	0.1364
1.9822	0.9369	0.7185	0.3736	0.1373
2.0715	0.9375	0.7207	0.3769	0.13995
2.155	0.9584	0.7811	0.4491	0.1847
2.28	0.9621	0.7947	0.4703	0.20176
2.393	0.98082	0.8621	0.5712	0.2798
2.424	0.9809	0.8629	0.5727	0.28147
2.532	0.9842	0.8781	0.6023	0.3113
2.714	0.9844	0.8789	0.6045	0.3142
3.1	0.9965	0.9666	0.8665	0.72
3.417	0.9997	0.9964	0.98199	0.9527

3.699	0.99999	0.9997	0.9989	0.9971
4.03	1	1	1	1

Table B.9 Results Obtained from Computer Program for:
$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$N_1 = 0.07$	$N_2 = 0.09$	$N_3 = 0.14$	$N_4 = 0.61$	$N_5 = 0.09$
$L_1 = 0.0246$	$L_2 = 0.042$	$L_3 = 0.0819$	$L_4 = 0.714$	$L_5 = 0.137$
$A_1 = 0.0077$	$A_2 = 0.0176$	$A_3 = 0.0428$	$A_4 = 0.746$	$A_5 = 0.186$
$V_1 = 0.00227$	$V_2 = 0.0069$	$V_3 = 0.021$	$V_4 = 0.7324$	$V_5 = 0.237$

Diameter of the pores (dc)	**Probability Due to Number(P_{rn})**	**Probability Due to Length(P_{rl})**	**Probability Due to Area (P_{ra})**	**Probability Due to Volume(P_{rv})**
0.93	3.43E-04	1.49E-05	4.57E-07	1.17E-08
1.0148	1.666E-03	9.13E-05	3.59E-06	1.18E-07
1.0779	3.724 E-03	2.4E-04	1.12E-05	4.43E-07
1.117	5.425 E-03	3.71E-04	1.84E-05	7.68E-07
1.1913	1.0717 E-02	8.81E-04	5.31E-05	2.75E-06
1.24	1.1446 E-02	9.56E-04	5.86E-05	3.08E-06
1.247	2.041 E-02	2.251E-03	1.91E-04	1.44E-05
1.277	2.453 E-02	2.747 E-03	2.34 E-04	1.74E-05
1.291	2.82 E-02	2.995 E-03	2.67 E-04	2.11E-05
1.328	2.92 E-02	3.432 E-03	3.06 E-04	2.41E-05
1.389	5.23 E-02	7.874 E-03	9.13 E-04	9.3E-05
1.43	5.76 E-02	8.724 E-03	1.01E-03	1.02 E-04
1.44	6.1 E-02	9.576 E-03	1.161 E-03	1.24 E-04
1.517	9.69 E-02	1.821E-02	2.635 E-03	3.34 E-04
1.55	0.996	1.876 E-02	2.714 E-03	3.43 E-04
1.57	0.1049	2.042 E-02	3.081 E-03	4.11 E-04
1.581	0.1197	2.423 E-02	3.775 E-03	5.16 E-04
1.6496	0.1219	2.496E-02	3.947 E-03	5.5 E-04
1.716	0.168	3.976 E-02	7.318 E-03	1.188 E-03
1.789	0.1748	4.26 E-02	8.158 E-03	1.395 E-03

1.861	0.25298	8.024 E-02	2.101E-02	5.046 E-03
1.89	0.2888	9.4634 E-02	2.5108 E-02	6.015 E-03
1.916	0.3119	0.10907	3.152 E-02	8.378 E-03
1.9822	0.3172	0.1118	3.2538 E-02	8.691 E-03
2.0715	0.3189	0.1132	3.334 E-02	9.074 E-03
2.155	0.4194	0.1777	6.271 E-02	2.0202 E-02
2.28	0.449	0.2025	7.736 E-02	2.7405 E-02
2.393	0.6053	0.3279	0.1488	6.1198 E-02
2.424	0.6075	0.33	0.1506	6.236 E-02
2.532	0.6536	0.3784	0.1862	8.423 E-02
2.714	0.657	0.383	0.1907	8.777 E-02
3.1	0.8839	0.7475	0.6057	0.4806
3.417	0.9844	0.9572	0.9161	0.862
3.699	0.99927	0.9974	0.9935	0.9854
4.03	1	1	1	1

Table B.10 Results Obtained from Computer Program for:
$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

N_1 = 0.035	N_2 = 0.045	N_3 = 0.09	N_4 = 0.68	N_5 = 0.15
L_1 = 0.1107	L_2 = 0.0189	L_3 =0.0474	L_4 = 0.717	L_5 = 0.2056
A_1 = 0.00325	A_2 = 0.0074	A_3 = 0.0232	A_4 = 0.701	A_5 = 0.261
V_1 = 0.00092	V_2 = 0.0028	V_3 = 0.0109	V_4 = 0.664	V_5 = 0.322

Diameter of the pores (dc)	Probability Due to Number(P_{rn})	Probability Due to Length(P_{rl})	Probability Due to Area (P_{ra})	Probability Due to Volume(P_{rv})
0.93	4.287E-05	1.36E-06	3.43E-08	7.79E-10
1.0148	2.083E-04	8.33E-06	2.69E-07	7.91E-09
1.0779	5.39E-04	2.58E-05	2.69E-07	3.58E-08
1.117	7.516E-04	3.77E-05	8.02E-07	5.76E-08
1.1913	1.602E-03	9.75E-05	4.15E-06	2.28E-07
1.24	1.693E-03	1.04E-04	4.55E-06	2.5E-07
1.247	4.192E-03	3.68 E-04	2.68E-05	1.94E-06
1.277	5.0427E-03	4.43 E-04	3.2E-05	2.27E-06

1.291	5.594E-03	5.18 E-04	4.03E-05	3.08E-06
1.328	6.141E-03	5.69 E-04	4.41E-05	3.34E-06
1.389	1.2567E-02	1.473E-03	1.45E-04	1.36E-05
1.43	0.01366	1.601 E-03	1.57 E-04	1.47E-05
1.44	0.01508	1.86 E-03	1.95 E-04	1.96E-05
1.517	0.02793	4.119 E-03	5.12 E-04	5.99E-05
1.55	0.02866	4.226 E-03	5.25 E-04	6.12E-05
1.57	0.03149	4.874 E-03	6.43 E-04	8.07E-05
1.581	0.0356	5.648 E-03	7.58 E-04	9.64E-05
1.6496	0.03654	5.87 E-03	8.01 E-04	1.04E-04
1.716	0.053	9.743 E-03	1.524E-03	2.27 E-04
1.789	0.0567	0.01085	1.793 E-03	2.86 E-04
1.861	0.1053	0.02792	6.588 E-03	1.502E-03
1.89	0.1218	0.03276	7.72 E-03	1.742 E-03
1.916	0.1432	0.04255	0.0113	2.92 E-03
1.9822	0.1468	0.04394	0.0117	3.037 E-03
2.0715	0.1492	0.04534	0.0124	3.22 E-03
2.155	0.2116	0.0746	0.0233	7.035 E-03
2.28	0.2392	0.09138	0.0315	0.01063
2.393	0.364	0.1645	0.0657	0.02514
2.424	0.367	0.16693	0.0672	0.02601
2.532	0.4221	0.20888	0.0927	0.04007
2.714	0.4282	0.21489	0.0975	0.04348
3.1	0.7426	0.58335	0.4425	0.33578
3.417	0.9507	0.90032	0.8284	0.76076
3.699	0.9966	0.9912	0.97228	0.9667
4.03	1	1	1	1

Table B.11 Results Obtained from Computer Program for:
$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$N_1 = 0.55$	$N_2 = 0.15$	$N_3 = 0.15$	$N_4 = 0.14$	$N_5 = 0.01$
$L_1 = 0.364$	$L_2 = 0.132$	$L_3 = 0.166$	$L_4 = 0.309$	$L_5 = 0.0287$
$A_1 = 0.185$	$A_2 = 0.0896$	$A_3 = 0.139$	$A_4 = 0.5225$	$A_5 = 0.063$
$V_1 = 0.0724$	$V_2 = 0.0468$	$V_3 = 0.0914$	$V_4 = 0.682$	$V_5 = 0.107$

Diameter of the pores (dc)	Probability Due to Number(P_{rn})	Probability Due to Length(P_{rl})	Probability Due to Area (P_{ra})	Probability Due to Volume(P_{rv})
0.93	0.1664	0.0483	6.308E-03	3.79E-04
1.0148	0.3025	0.10103	0.01548	1.115E-03
1.0779	0.4386	0.1669	0.02982	2.551 E-03
1.117	0.4757	0.18609	0.03427	3.026 E-03
1.1913	0.55	0.23402	0.04817	4.883 E-03
1.24	0.5534	0.2363	0.04889	4.986 E-03
1.247	0.6804	0.3593	0.1024	0.0157
1.277	0.7176	0.3893	0.11327	0.01752
1.291	0.7266	0.4007	0.11973	0.0192
1.328	0.7368	0.4094	0.1231	0.01981
1.389	0.806	0.4988	0.17499	0.03367
1.43	0.8162	0.5097	0.18026	0.03484
1.44	0.8211	0.518	0.1865	0.03702
1.517	0.8904	0.6298	0.2676	0.0641
1.55	0.8938	0.6344	0.2704	0.06486
1.57	0.8988	0.6447	0.28016	0.0691
1.581	0.9082	0.661	0.2927	0.0736
1.6496	0.9089	0.6625	0.29425	0.0743
1.716	0.9278	0.7032	0.33357	0.0918
1.789	0.9291	0.7069	0.3383	0.09455
1.861	0.9615	0.8113	0.48969	0.19566
1.89	0.9709	0.8367	0.5204	0.2128
1.916	0.9755	0.85607	0.5569	0.24448
1.9822	0.9762	0.8584	0.5607	0.24717
2.0715	0.9764	0.8593	0.56287	0.24966
2.155	0.98519	0.89727	0.6363	0.315
2.28	0.9865	0.9043	0.6539	0.3355
2.393	0.9952	0.9517	0.7687	0.46318
2.424	0.9953	0.9521	0.7697	0.4648
2.532	0.9966	0.9609	0.7974	0.5049
2.714	0.99662	0.9613	0.79908	0.50799
3.1	0.9994	0.9908	0.9418	0.8257
3.417	0.99996	0.999	0.99347	0.9753
3.699	0.99999	0.9998	0.9997	0.99876

4.03	1	1	1	1

Table B.12 Results Obtained from Computer Program for:
$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$N_1 = 0.03$	$N_2 = 0.04$	$N_3 = 0.09$	$N_4 = 0.64$	$N_5 = 0.2$
$L_1 = 0.0093$	$L_2 = 0.0165$	$L_3 = 0.046$	$L_4 = 0.659$	$L_5 = 0.268$
$A_1 = 0.00928$	$A_2 = 0.0063$	$A_3 = 0.022$	$A_4 = 0.634$	$A_5 = 0.335$
$V_1 = 0.00074$	$V_2 = 0.0023$	$V_3 = 0.0103$	$V_4 = 0.585$	$V_5 = 0.402$

Diameter of the pores (dc)	**Probability Due to Number(P_{rn})**	**Probability Due to Length(P_{rl})**	**Probability Due to Area (P_{ra})**	**Probability Due to Volume(P_{rv})**
0.93	2.7E-05	7.99E-07	1.91E-08	4.05E-10
1.0148	1.35E-04	5.06E-06	1.55E-07	4.25E-09
1.0779	3.78 E-04	1.7E-05	6.33E-07	2.11E-08
1.117	5.22 E-04	2.46E-05	9.55E-07	3.33E-08
1.1913	1.17E-03	6.72E-05	3.22E-06	1.4E-07
1.24	1.234 E-03	7.17E-05	3.48E-06	1.53E-07
1.247	2.962 E-03	2.42E-04	1.71E-05	1.11E-06
1.277	3.691 E-03	3.02 E-04	2.11E-05	1.35E-06
1.291	4.231 E-03	3.71 E-04	2.82E-05	2.01E-06
1.328	4.663 E-03	4.09 E-04	3.09E-05	2.18E-06
1.389	9.271 E-03	1.015E-03	9.54E-05	8.25E-06
1.43	0.0102	1.121 E-03	1.05E-04	9E-06
1.44	0.0117	1.367 E-03	1.39 E-04	1.32E-05
1.517	0.022	3.071 E-03	3.66 E-04	3.99E-05
1.55	0.0228	3.171 E-03	3.77 E-04	4.1E-05
1.57	0.026	3.863 E-03	4.96 E-04	5.93E-05
1.581	0.0291	4.401 E-03	5.73 E-04	6.89E-05
1.6496	0.03005	4.62 E-03	6.13 E-04	7.55E-05
1.716	0.04387	7.648 E-03	1.15E-03	1.6 E-04
1.789	0.04819	8.878 E-03	1.434 E-03	2.18 E-04
1.861	0.085	0.020995	4.658 E-03	9.78 E-04
1.89	0.1006	0.02526	5.602 E-03	1.163 E-03

1.916	0.1237	0.0351	9.007 E-03	2.206 E-03
1.9822	0.1285	0.03683	9.506 E-03	2.334 E-03
2.0715	0.1321	0.03883	0.010405	2.692 E-03
2.155	0.1813	0.06036	0.01805	5.094 E-03
2.28	0.21198	0.07786	0.0261	8.392 E-03
2.393	0.3226	0.13844	0.05298	0.018946
2.424	0.327	0.141995	0.0551	0.02019
2.532	0.3965	0.1912	0.08349	0.03457
2.714	0.4073	0.2012	0.09099	0.0395
3.1	0.6694	0.4884	0.3457	0.23974
3.417	0.9152	0.8384	0.74928	0.65205
3.699	0.992	0.9806	0.9624	0.93510
4.03	1	1	1	1

Table B.13 Results Obtained from Computer Program for:
$d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26$

N_1=0.65	N_2=0.15	N_3=0.075	N_4=0.115	N_5=0.01
L_1=0.464	L_2= 0.143	L_3= 0.0892	L_4= 0.273	L_5= 0.0309
A_1= 0.2509	A_2= 0.1029	A_3= 0.0804	A_4= 0.493	A_5= 0.0724
V_1= 0.1011	V_2= 0.055	V_3= 0.054	V_4= 0.663	V_5= 0.127

Diameter of the pores (dc)	**Probability Due to Number(P_{rn})**	**Probability Due to Length(P_{rl})**	**Probability Due to Area (P_{ra})**	**Probability Due to Volume(P_{rv})**
0.93	0.275	0.0997	1.579 E-02	1.035E-03
1.0148	0.465	0.19178	3.52 E-02	2.73 E-03
1.0779	0.5598	0.2493	5.042 E-02	4.39 E-03
1.117	0.6037	0.2776	5.8399 E-02	5.32 E-03
1.1913	0.6476	0.3130	7.086 E-02	7.13 E-03
1.24	0.65	0.3159	7.195 E-02	7.3 E-03
1.247	0.7967	0.49237	0.1651	2.76E-02
1.277	0.8077	0.5034	0.1699	2.85 E-02
1.291	0.8203	0.52338	0.1837	3.24 E-02
1.328	0.8254	0.5288	0.1862	3.29 E-02

1.389	0.8927	0.6374	0.2626	5.517 E-02
1.43	0.8952	0.6408	0.2646	5.566 E-02
1.44	0.9011	0.65308	0.2759	5.99 E-02
1.517	0.9347	0.7209	0.3356	8.163 E-02
1.55	0.9351	0.7216	0.3361	8.179 E-02
1.57	0.938	0.7293	0.3449	8.59 E-02
1.581	0.9458	0.74602	0.3605	9.203 E-02
1.6496	0.9465	0.7479	0.3628	9.319 E-02
1.716	0.9542	0.76879	0.3873	0.1051
1.789	0.9549	0.7711	0.3909	0.1073
1.861	0.9807	0.8752	0.57403	0.24065
1.89	0.9826	0.8817	0.58359	0.24645
1.916	0.9871	0.90525	0.6374	0.29738
1.9822	0.9873	0.9059	0.6388	0.29849
2.0715	0.98749	0.9073	0.64277	0.30335
2.155	0.9935	0.9393	0.71789	0.37627
2.28	0.9945	0.9466	0.73997	0.40413
2.393	0.99746	0.9666	0.79864	0.4753
2.424	0.9975	0.96699	0.8003	0.47795
2.532	0.99802	0.9715	0.8175	0.50514
2.714	0.99805	0.97177	0.81877	0.5077
3.1	0.9996	0.9922	0.9387	0.7989
3.417	0.99996	0.99916	0.9916	0.9658
3.699	0.99999	0.9999	0.9994	0.9976
4.03	1	1	1	1

Now to calculate the mean diameter (dc_m)due to number ,length, surface area and volume equation (2.7) must be applied ,so the results of the main diameter were (dc_m) also computed by computer program in appendix [D].

Table B.14 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.1, N_2 = 0.1, N_3 = 0.2, N_4 = 0.54, N_5 = 0.06}$$

Mean pore diameter due to number	2.2045
Mean pore diameter due to length	2.683
Mean pore diameter due to area	2.999
Mean pore diameter due to volume	3.204

Table B.15 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.15, N_2 = 0.15, N_3 = 0.2, N_4 = 0.44, N_5 = 0.06}$$

Mean pore diameter due to number	1.978
Mean pore diameter due to length	2.613
Mean pore diameter due to area	2.915
Mean pore diameter due to volume	3.184

Table B.16 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.2, N_2 = 0.2, N_3 = 0.15, N_4 = 0.43, N_5 = 0.02}$$

Mean pore diameter due to number	1.819
Mean pore diameter due to length	2.389
Mean pore diameter due to area	2.783
Mean pore diameter due to volume	2.027

Table B.17 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.25, N_2 = 0.2, N_3 = 0.182, N_4 = 0.348, N_5 = 0.02}$$

Mean pore diameter due to number	1.759
Mean pore diameter due to length	2.182
Mean pore diameter due to area	2.668
Mean pore diameter due to volume	2.949

Table B.18 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.4, N_2 = 0.2, N_3 = 0.15, N_4 = 0.23, N_5 = 0.02}$$

Mean pore diameter due to number	1.418
Mean pore diameter due to length	1.879
Mean pore diameter due to area	2.457
Mean pore diameter due to volume	2.893

Table B.19 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.05, N_2 = 0.06, N_3 = 0.09, N_4 = 0.7, N_5 = 0.1}$$

Mean pore diameter due to number	2.685
Mean pore diameter due to length	3.015
Mean pore diameter due to area	3.191
Mean pore diameter due to volume	3.292

Table B.20 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.5, N_2 = 0.132, N_3 = 0.118, N_4 = 0.23, N_5 = 0.02}$$

Mean pore diameter due to number	1.365
Mean pore diameter due to length	1.855
Mean pore diameter due to area	2.474
Mean pore diameter due to volume	2.928

Table B.21 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.07, N_2 = 0.09, N_3 = 0.14, N_4 = 0.61, N_5 = 0.09}$$

Mean pore diameter due to number	2.479
Mean pore diameter due to length	2.867
Mean pore diameter due to area	3.119
Mean pore diameter due to volume	3.274

Table B.22 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.035, N_2 = 0.045, N_3 = 0.09, N_4 = 0.68, N_5 = 0.15}$$

Mean pore diameter due to number	2.858
Mean pore diameter due to length	3.105
Mean pore diameter due to area	3.268
Mean pore diameter due to volume	3.364

Table B.23 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.55, N_2 = 0.15, N_3 = 0.15, N_4 = 0.14, N_5 = 0.01}$$

Mean pore diameter due to number	1.236
Mean pore diameter due to length	1.572
Mean pore diameter due to area	2.171
Mean pore diameter due to volume	2.663

Table B.24 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.03, N_2 = 0.04, N_3 = 0.09, N_4 = 0.64, N_5 = 0.2}$$

Mean pore diameter due to number	2.597
Mean pore diameter due to length	3.169
Mean pore diameter due to area	3.332
Mean pore diameter due to volume	3.431

Table B.25 Values of Mean Pore Diameter for:

$$\mathbf{d_1 = 6, d_2 = 8, d_3 = 10, d_4 = 20, d_5 = 26}$$

$$\mathbf{N_1 = 0.65, N_2 = 0.15, N_3 = 0.075, N_4 = 0.115, N_5 = 0.01}$$

Mean pore diameter due to number	1.154
Mean pore diameter due to length	1.452
Mean pore diameter due to area	2.019
Mean pore diameter due to volume	2.636

B.2.1Theortical Resluts(Porosity for Mono System).

At Packed bed composed of spheres of five diameters (6, 8, 10, 20, and 26) porosity of each diameter could be calculated theoretically by using Furnas equation (2.9) for mono size system.

Table B.26 Porosity Calculated for Mono System by Using Furnas Equation.

Ratio d/D in the Cylinder of Diameter 12.9cm	Porosity	Ratio d/D in the Cylinder of Diameter 6.4 cm	Porosity
0.0465	0.3908	0.09375	0.4069
0.062	0.39608	0.125	0.4175
0.0775	0.4013	0.15625	0.428
0.15503	0.4277	0.3125	0.4812
0.20155	0.4435	0.40625	0.5131

B.2.2Theortical Resluts (Porosity for Binary System).

Table B.27 Calculated Values of Porosity for Binary System d1=26, d2=6 mm

Wight Percent of Sphere with d2=6	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.4236	0.1492
90%	0.8855	0.416	0.1675
80%	0.7746	0.3985	0.1869
70%	0.6672	0.3767	0.2078
60%	0.5631	0.3545	0.2297
50%	0.5	0.3354	0.2439
40%	0.3642	0.3231	0.277
30%	0.2691	0.305	0.3023
20%	0.1768	0.3379	0.3285
10%	0.087	0.3722	0.355

Table B.28 Calculated Values of Porosity for Binary System d1=20, d2=6 mm.

Wight Percent of Sphere with d2=6	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.41196	0.1912
90%	0.8919	0.4063	0.2154
80%	0.7858	0.3925	0.225
70%	0.6815	0.3745	0.2431
60%	0.579	0.3557	0.2619
50%	0.4783	0.339	0.2813
40%	0.3794	0.3279	0.3014
30%	0.2821	0.3266	0.322
20%	0.1865	0.339	0.343
10%	0.0925	0.3678	0.3644

Table B.29 Calculated Values of Porosity for Binary system d1=10, d2=6 mm.

Wight Percent of Sphere with d2=6	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.4034	0.3677
90%	0.8936	0.4009	0.3729
80%	0.7887	0.3945	0.3776
70%	0.6853	0.3858	0.38185
60%	0.5833	0.3765	0.38549
50%	0.4828	0.3687	0.38855
40%	0.3836	0.36403	0.39097
30%	0.2857	0.3644	0.3927
20%	0.1892	0.37095	0.3937
10%	0.09396	0.3842	0.394

Table B.30 Calculated Values of Porosity for Binary System d1=8, d2=6 mm.

Wight Percent of Sphere with d2=6	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.3974	0.45386
90%	0.8919	0.3959	0.45035
80%	0.7858	0.39212	0.446
70%	0.6815	0.3869	0.4418
60%	0.579	0.3815	0.4367
50%	0.4783	0.3769	0.4312
40%	0.3738	0.37441	0.42488
30%	0.28209	0.3751	0.4187
20%	0.1865	0.3791	0.41169
10%	0.0925	0.3871	0.40417

Table B.31 Calculated Values of Porosity for Binary System d1=26, d2=8

Wight Percent of Sphere with d2=8	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.4262	0.1958
90%	0.894	0.4208	0.2195
80%	0.7894	0.4074	0.2287
70%	0.6862	0.3898	0.2463
60%	0.5843	0.371	0.2646
50%	0.4838	0.3542	0.2836
40%	0.3845	0.3428	0.30329
30%	0.2866	0.3409	0.32346
20%	0.1898	0.3529	0.34409
10%	0.0943	0.3816	0.36508

Table B.32 Calculated Values of Porosity for Binary System d1=20, d2=8

Wight Percent of Sphere with d2=8	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.4146	0.2508
90%	0.9	0.4107	0.27275
80%	0.8	0.4008	0.27708
70%	0.7	0.3872	0.2907
60%	0.6	0.3722	0.30458
50%	0.5	0.3582	0.31867
40%	0.4	0.3486	0.33289
30%	0.3	0.3465	0.34716
20%	0.2	0.3555	0.36138
10%	0.1	0.3783	0.3754

Table B.33 Calculated Values of Porosity for Binary System d1=10, d2=8

Wight Percent of Sphere with d2=8	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.406	0.48236
90%	0.9016	0.405	0.47621
80%	0.8028	0.4024	0.469585
70%	0.7037	0.3986	0.46247
60%	0.6043	0.3944	0.4548
50%	0.5044	0.39064	0.44666
40%	0.4043	0.3883	0.43792
30%	0.3037	0.3881	0.4286
20%	0.2029	0.3909	0.418686
10%	0.1016	0.3969	0.40818

Table B.34 Calculated Values of Porosity for Binary System d1=26, d2=10.

Wight Percent of Sphere with d2=10	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.4322	0.2417
90%	0.8923	0.4276	0.26557
80%	0.7864	0.4156	0.270856
70%	0.6824	0.4007	0.28572
60%	0.58	0.3845	0.30072
50%	0.479	0.3705	0.31573
40%	0.3803	0.3615	0.33078
30%	0.2829	0.36104	0.34568
20%	0.1871	0.3721	0.360376
10%	0.093	0.3962	0.37476

Table B.35 Calculated Values of Porosity for Binary System d1=20, d2=10.

Wight Percent of Sphere with d2=10	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.4206	0.30959
90%	0.898	0.4175	0.31919
80%	0.7971	0.4096	0.32859
70%	0.6963	0.3985	0.3378
60%	0.5957	0.3864	0.346846
50%	0.4956	0.3755	0.3555
40%	0.3958	0.3683	0.36386
30%	0.2963	0.3675	0.37172
20%	0.1972	0.3764	0.379
10%	0.098	0.3932	0.3857

Table B.36 Calculated Values of Porosity for Binary System d1=26, d2=20.

Wight Percent of Sphere with d2=20	V2	Calculated Porosity Using Jeschar Equation	Calculated Porosity Using Latif Equation
100%	1	0.4407	0.46483
90%	0.894	0.4394	0.4608
80%	0.7894	0.4359	0.45505
70%	0.6862	0.431	0.44944
60%	0.5843	0.4259	0.4433
50%	0.4838	0.4216	0.43676
40%	0.3845	0.4191	0.42969
30%	0.2865	0.4195	0.422125
20%	0.1898	0.4232	0.414064
10%	0.094	0.4305	0.405504

APPENDIX[C]

C.1 Experimental Resluts For Pore Size.

The results of the experiments are given below in detail:-

Experiment 1

Table C.1 Results of Exp .1

Diameter of Sphere (mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.1	39
8	193	0.1	19
10	125	0.2	25
20	29	0.54	16
26	19	0.06	1

No. of layers		**2**	**3**	**4**
Size of Impurities (mm)	**Weight of Spheres Input(gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**	**Weight Of Spheres Out put (gm)**
1.2-2	31.2	30.9	26	24.5
2-2.36	144	138.9	117.5	60
2.36-3.15	45.7	40	32	17
Height of the Bed (cm)		3.2	4.5	5.8

No. of Layers	**2**	**3**	**4**
Size of Impurities (mm)	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**
1.2-2	99	83.33	78.53
2-2.36	96.46	81.597	41.67
2.36-3.15	87.53	70	37.199
Porosity	0.497	0.47	0.451

Experiment 2

Table C.2 Results of Exp .2

Diameter of sphere (mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.15	58
8	193	0.15	29
10	125	0.2	25
20	29	0.44	13
26	19	0.06	1

No. of Layers		2	3	4
Size of Impurities (mm)	Weight of Spheres Input (gm)	Weight of Spheres Out put (gm)	Weight of Spheres Out put (gm)	Weight of Spheres Out put (gm)
1.2-2	31.2	30.7	26	24.5
2-2.36	144	133	115.2	57
2.36-3.15	45.7	38	30	16
Height of the bed (cm)		2.8	4	5.5

No. of Layers	2	3	4
Size of Impurities (mm)	Percent Output (Wt. %)	Percent Output (Wt. %)	Percent Output (Wt. %)
1.2-2	98.39	81.73	64.1
2-2.36	92.36	80	39.833
2.36-3.15	83.15	65.65	35
Porosity	0.479	0.467	0.449

Experiment 3

Table C.3 Results of Exp .3

Diameter of sphere(mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.2	77
8	193	0.2	39
10	125	0.15	19
20	29	0.43	13
26	19	0.02	1

No. of layers		2	3	4
Size of Impurities (mm)	Weight of Spheres Input (gm)	Weight of Spheres Out put (gm)	Weight of Spheres Out put (gm)	Weight of Spheres Out put (gm)
1.2-2	31.2	30.5	25	19
2-2.36	144	126	110	53.7
2.36-3.15	45.7	37.9	29.3	15.6
Height of the Bed (cm)		2.7	4	5.2

No. of Layers	2	3	4
Size of Impurities (mm)	Percent Output (Wt. %)	Percent Output (Wt. %)	Percent Output (Wt. %)
1.2-2	97.75	80.128	60.89
2-2.36	87.5	76.39	37.29
2.36-3.15	82.93	64.11	34.14
Porosity	0.45	0.444	0.429

Experiment 4

Table C.4 Results of Exp .4

Diameter of Sphere(mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.25	97
8	193	0.2	39
10	125	0.182	23
20	29	0.348	10
26	19	0.02	1

No. of layers		2	3	4
Size of Impurities (mm)	Weight of spheres Input (gm)	Weight of spheres out put (gm)	Weight of spheres out put (gm)	Weight of spheres out put (gm)
1.2-2	31.2	30.1	23.5	18.8
2-2.36	144	125.8	100	50
2.36-3.15	45.7	35.6	22	13.9
Height of the Bed (cm)		2.4	3.5	4.6

No. of layers	2	3	4
Size of Impurities (mm)	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**
1.2-2	96.47	75.32	60.25
2-2.36	87.36	69.44	34.72
2.36-3.15	77.89	48.14	30.42
Porosity	0.44	0.424	0.416

<u>Experiment 5 ;</u>

Table C.5 Results of Exp .5

Diameter of Sphere(mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.4	154
8	193	0.2	39
10	125	0.15	19
20	29	0.23	7
26	19	0.02	1

No. of layers		**2**	**3**	**4**
Size of Impurities (mm)	**Weight of Spheres Input (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**
1.2-2	31.2	29	21	16
2-2.36	144	115	80	45
2.36-3.15	45.7	33.3	20	12
Height of the Bed (cm)		2.1	3.1	4

No. of Layers	**2**	**3**	**4**
Size of Impurities (mm)	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**
1.2-2	92.95	67.31	52.24
2-2.36	79.86	55.56	31.25
2.36-3.15	72.87	43.76	26.26
Porosity	0.427	0.418	0.399

Experiment 6

Table C.6 Results of Exp .6

Diameter of Sphere(mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.05	19
8	193	0.06	12
10	125	0.09	11
20	29	0.7	20
26	19	0.1	2

No. of layers		**2**	**3**	**4**
Size of Impurities (mm)	**Weight of Spheres Input (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**
1.2-2	31.2	31.2	27	26
2-2.36	144	142	122	117.2
2.36-3.15	45.7	42.3	35.8	28.6
Height of the Bed (cm)		3.8	5.4	7.1

No. of layers	**2**	**3**	**4**
Size of Impurities (mm)	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**
1.2-2	100	86.54	83.33
2-2.36	98.61	84.22	81.39
2.36-3.15	92.56	78.34	62.58
Porosity	0.518	0.49	0.484

Experiment 7

Table C.7 Results of Exp .7

Diameter of Sphere(mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.5	193
8	193	0.132	26
10	125	0.118	15
20	29	0.32	7
26	19	0.02	1

No. of layers		**2**	**3**	**4**
Size of Impurities (mm)	**Weight of Spheres Input (gm)**	**Weight of Spheres Out put (gm)**	**Weight Of Spheres Out put (gm)**	**Weight Of Spheres out put (gm)**
1.2-2	31.2	26	19	11.9
2-2.36	144	110	62	34
2.36-3.15	45.7	32	18	10
Height of the bed (cm)		2	2.9	3.8

No. of layers	**2**	**3**	**4**
Size of impurities (mm)	**Percent output (Wt. %)**	**Percent output (Wt. %)**	**Percent output (Wt. %)**
1.2-2	83.33	60.9	38.14
2-2.36	76.39	43	23.61
2.36-3.15	70	39.39	21.88
Porosity	0.408	0.387	0.376

Experiment 8

Table C.8 Results of Exp .8

Diameter of Sphere(mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.07	27
8	193	0.09	17
10	125	0.14	18
20	29	0.61	18
26	19	0.09	2

No. of layers		2	3	4
Size of Impurities (mm)	**Weight of Spheres Input (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**
1.2-2	31.2	31	26.5	25
2-2.36	144	140	118	100
2.36-3.15	45.7	41	33	25
Height of the Bed (cm)		3.6	5.2	6.5

No. of Layers	2	3	4
Size of Impurities (mm)	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**
1.2-2	99.36	84.9	80.13
2-2.36	97.22	81.94	69.44
2.36-3.15	89.72	72.21	54.7
Porosity	0.504	0.485	0.475

Experiment 9

Table C.9 Results of Exp .9

Diameter of Sphere(mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.035	14
8	193	0.045	9
10	125	0.09	11
20	29	0.68	20
26	19	0.15	3

No. of Layers		**2**	**3**	**4**
Size of Impurities (mm)	**Weight of Spheres Input (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**
1.2-2	31.2	31	28	26.5
2-2.36	144	143	126	120
2.36-3.15	45.7	43	36	29
Height of the Bed (cm)		4.2	6	7.8

No. of Layers	**2**	**3**	**4**
Size of Impurities (mm)	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**
1.2-2	100	89.74	84.94
2-2.36	99.3	87.5	83.33
2.36-3.15	94.1	78.77	63.46
Porosity	0.535	0.512	0.499

Experiment 10

Table C.10 Results of Exp .10

Diameter of Sphere(mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.55	212
8	193	0.15	29
10	125	0.15	19
20	29	0.14	4
26	19	0.01	1

No. of layers		**2**	**3**	**4**
Size of Impurities (mm)	**Weight of Spheres Input (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**
1.2-2	31.2	23.6	16	8.4
2-2.36	144	105	50	27.6
2.36-3.15	45.7	30	15	7.2
Height of the Bed (cm)		1.9	2.8	3.6

No. of Layers	**2**	**3**	**4**
Size of Impurities (mm)	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**
1.2-2	75.64	51.28	26.92
2-2.36	72.92	34.72	19.17
2.36-3.15	65.65	32.82	15.75
Porosity	0.385	0.374	0.35

Experiment 11

Table C.11 Results of Exp .11

Diameter of Sphere(mm)	Number of Sphere Cover the Base of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.03	12
8	193	0.04	8
10	125	0.09	11
20	29	0.64	19
26	19	0.2	4

No. of Layers		2	3	4
Size of Impurities (mm)	**Weight of Spheres Input (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**
1.2-2	31.2	31.2	29.7	28.7
2-2.36	144	144	140	125
2.36-3.15	45.7	43	36	9
Height of the Bed (cm)		4.4	6.5	8.4

No. of layers	2	3	4
Size of Impurities (mm)	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**
1.2-2	100	95.19	91.99
2-2.36	100	97.22	86.8
2.36-3.15	96.28	85.34	67.83
Porosity	0.535	0.512	0.499

Experiment 12

Table C.12 Results of Exp .12

Diameter of Sphere(mm)	Number of Sphere Cover the Case of Cylinder	Number Percent of Sphere(N)	Number of Spheres in Each Layer
6	387	0.03	12
8	193	0.04	8
10	125	0.09	11
20	29	0.64	19
26	19	0.2	4

No. of Layers		**2**	**3**	**4**
Size of Impurities (mm)	**Weight of Spheres Input (gm)**	**Weight of Spheres Out put (gm)**	**Weight of Spheres Out put (gm)**	**Weight Of Spheres Out put (gm)**
1.2-2	31.2	22	15.5	8
2-2.36	144	100	45	26
2.36-3.15	45.7	28	12	6.5
Height of the Bed (cm)		1.5	2.2	2.9

No. of layers	**2**	**3**	**4**
Size of Impurities (mm)	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**	**Percent Output (Wt. %)**
1.2-2	70.51	49.68	25.64
2-2.36	69.44	31.25	18.06
2.36-3.15	61.27	26.26	14.22
Porosity	0.346	0.331	0.323

C.2.1 Experimental Resluts (Porosity for mono system)

Table C.13 Height of Sphere in The Cylinders of Diameter 12.9 cm and 6.4 cm .

No.	Diameter of spheres (mm)	Height (L) (cm) In the Cylinder of diameter 12.9 cm	Height (L) (cm) In the Cylinder of diameter 6.4 cm
1	6	1.5	42
2	8	2.62	29.96
3	10	3.128	13.5
4	20	6.59	11.2
5	26	9	6.3

Table C.14 Porosity in The Cylinders of Diameters 12.9 cm and 6.4cm.

No.	Diameter of spheres (mm)	Porosity In the Cylinder of diameter 12.9 cm	Porosity In the Cylinder of diameter 6.4 cm
1	6	0.395	0.415
2	8	0.4	0.43
3	10	0.412	0.447
4	20	0.429	0.49
5	26	0.452	0.523

C.2.2 Experimental Resluts (Porosity for Binary System).

Table C.15 Experimentally Porosity for Binary systemd1=26,d2=6 mm.

V_2	N_1	N_2	L(cm)	$V_T\ (cm^3)$	Porosity
1	0	978	1.6	209.01	0.471
0.8855	1	880	1.5	195.948	0.4454
0.7746	3	782	1.5	195.948	0.408
0.6672	4	684	1.5	195.948	0.4176
0.5631	6	587	1.5	195.948	0.3797
0.5	7	489	1.5	195.948	0.3893
0.3642	8	391	1.5	195.948	0.3989
0.2691	10	293	1.5	195.948	0.3616
0.1768	11	196	1.6	209.01	0.4099
0.087	13	98	1.8	235.137	0.4443

Table C.16 Experimentally Porosity for Binary System d1=20,d2=6 mm.

V_2	N_1	N_2	L(cm)	$V_T\ (cm^3)$	Porosity
1	0	978	1.6	209.01	0.471
0.8919	3	880	1.5	195.948	0.4233
0.7858	5	782	1.5	195.948	0.4338
0.6815	8	684	1.4	182.88	0.38
0.579	11	587	1.5	195.948	0.4083
0.4783	13	489	1.4	182.88	0.3773
0.3794	16	391	1.4	182.88	0.364
0.2821	19	293	1.5	195.948	0.3938
0.1865	21	196	1.5	195.948	0.4037
0.0925	24	98	1.6	209.01	0.429

Table C.17 Experimentally Porosity for binarySystemd1=10,d2=6 mm

V_2	N_1	N_2	L(cm)	$V_T\,(cm^3)$	Porosity
1	0	978	1.6	209.01	0.471
0.8936	23	880	1.65	215.54	0.4826
0.7887	45	782	1.7	222.07	0.496
0.6853	68	684	1.6	209.01	0.459
0.5833	91	587	1.6	209.01	0.455
0.4828	113	489	1.5	195.948	0.4161
0.3836	135	391	1.55	202.48	0.4328
0.2857	158	293	1.55	202.48	0.428
0.1892	181	196	1.6	209.01	0.4408
0.09396	203	98	1.65	215.54	0.4557

Table C.18 Experimentally Porosity for Binary System d1=8,d2=6 mm.

V_2	N_1	N_2	L(cm)	$V_T\,(cm^3)$	Porosity
1	0	978	1.6	209.01	0.471
0.8919	45	880	1.65	215.54	0.483
0.7858	90	782	1.6	209.01	0.462
0.6815	135	684	1.6	209.01	0.457
0.579	180	587	1.55	202.48	0.434
0.4783	225	489	1.6	209.01	0.447
0.3738	270	391	1.6	209.01	0.442
0.28209	315	293	1.6	209.01	0.438
0.1865	360	196	1.65	215.54	0.449
0.0925	405	98	1.7	222.07	0.462

Table C.19 Experimentally Porosity for Binary System d1=26,d2=8 mm.

V_2	N_1	N_2	L(cm)	V_T (cm^3)	Porosity
1	0	450	1.8	235.137	0.4872
0.894	1	405	1.7	222.07	0.4699
0.7894	3	360	1.7	222.07	0.4416
0.6862	4	315	1.6	209.01	0.4233
0.5843	6	270	1.6	209.01	0.3899
0.4838	7	225	1.6	209.01	0.4036
0.3845	8	180	1.5	195.948	0.378
0.2866	10	135	1.6	209.01	0.3869
0.1898	11	90	1.7	222.07	0.4358
0.0943	13	45	1.8	235.137	0.4402

Table C.20 Experimentally Porosity for Binary System d1=20,d2=8 mm.

V_2	N_1	N_2	L(cm)	V_T (cm^3)	Porosity
1	0	450	1.8	235.137	0.4872
0.9	3	405	1.8	235.137	0.4809
0.8	5	360	1.8	235.137	0.494
0.7	8	315	1.7	222.07	0.458
0.6	11	270	1.7	222.07	0.451
0.5	13	225	1.55	202.48	0.4129
0.4	16	180	1.55	202.48	0.4057
0.3	19	135	1.55	202.48	0.3984
0.2	21	90	1.55	202.48	0.4133
0.1	24	45	1.55	202.48	0.442

Table C.21 Experimentally Porosity for Binary System d1=10,d2=8 mm.

V_2	N_1	N_2	L(cm)	$V_T\,(cm^3)$	Porosity
1	0	450	1.8	235.137	0.4872
0.9016	23	405	1.8	235.137	0.4881
0.8028	45	360	1.7	222.07	0.4592
0.7037	68	315	1.7	222.07	0.46
0.6043	91	270	1.7	222.07	0.461
0.5044	113	225	1.6	209.01	0.428
0.4043	135	180	1.6	209.01	0.4295
0.3037	158	135	1.6	209.01	0.4305
0.2029	181	90	1.6	209.01	0.4315
0.1016	203	45	1.6	209.01	0.4325

Table C.22 Experimentally Porosity for Binary Systemd1=26,d2=10 mm.

V_2	N_1	N_2	L(cm)	$V_T\,(cm^3)$	Porosity
1	0	226	1.8	235.137	0.4965
0.8923	1	204	1.7	222.07	0.4787
0.7864	3	181	1.7	222.07	0.4492
0.6824	4	158	1.7	222.07	0.4611
0.58	6	135	1.7	222.07	0.4316
0.479	7	113	1.7	222.07	0.4387
0.3803	8	91	1.6	209.01	0.421
0.2829	10	68	1.7	222.07	0.4259
0.1871	11	45	1.7	222.07	0.4377
0.093	13	23	1.8	235.137	0.4411

Table C.23 Experimentally Porosity for Binary System d1=20,d2=10 mm.

V_2	N_1	N_2	L(cm)	$V_T\,(cm^3)$	Porosity
1	0	226	1.8	235.137	0.496
0.898	3	204	1.7	222.07	0.466
0.7971	5	181	1.7	222.07	0.465
0.6963	8	158	1.7	222.07	0.464
0.5957	11	135	1.6	209.01	0.429
0.4956	13	113	1.6	209.01	0.424
0.3958	16	91	1.6	209.01	0.428
0.2963	19	68	1.6	209.01	0.427
0.1972	21	45	1.6	209.01	0.426
0.098	24	23	1.6	209.01	0.425

Table C.24 Experimentally Porosity for Binary System d1=26,d2=20 mm.

V_2	N_1	N_2	L(cm)	$V_T\,(cm^3)$	Porosity
1	0	27	1.8	235.137	0.488
0.894	1	24	1.7	222.07	0.479
0.7894	3	21	1.8	235.137	0.479
0.6862	4	19	1.8	235.137	0.491
0.5843	6	16	1.9	248.2	0.491
0.4838	7	13	1.9	248.2	0.498
0.3845	8	11	1.8	235.14	0.486
0.2865	10	8	1.8	235.14	0.458
0.1898	11	5	1.8	235.14	0.469
0.094	13	3	2	261.2	0.497

APPENDIX [D]
COMPUTER PROGRAM

Program number one

```
REM ***************************************************************
REM******PROGRAM USED TO CALCULATE THE PORE***********
REM******SIZEOF FIVE VALUES OF PARTICULATE DIAMETER****
REM****************************************************************
CLS
DIM N (5)
F=J
For I=1 to 5
READ N (I)
NEXT I
5 PRINT"INPUT THE DIAMETER VALUES"
DATA 0.6, 0.8, 1, 2, 2.6
DIM X (3)
For I=1 to 3
Input X (I)
NEXT I
For I=1 to 2
For J=1 to 3-I
If x (J) <x (J+1) THEN 10
T=x (J): x (J) =x (J+1): x (J+1) =T
10 NEXT: NEXT
For I=1 to 3
PRINT x (I)
Next I
DK=X (1): DM=X (2): DG=X (3)
IF X (1) =X (2) AND X (2) =X (3) THEN 20
IF DK=DM AND DK <DG THEN 30
IF DG=DM AND DG>DK THEN 40
IF DK<>DM AND DM<>DG THEN 50
20 PRINT "THREE EQUAL DIAMETERS"
DP1=0.155*DG
Z (F) =DP1
PRINT"DP1="; DP1
GOTO 60
30 PRINT "TWO SMALL DIAMETER AND ONE LARGE"
A=DK/DG
```

```
B= (((2*A) + (A^2)) ^ (1/2)-A)
C= (2+ (2*B))
DP2= ((B^2)/C)*DG
Z (F) =DP2
PRINT "DP2="; DP2
GOTO 60
40 PRINT "TWO LARGE DIAMETERS AND ONE SMALL"
A=DK/DG
D= (((2/a) + (A^-2)) ^ (1/2))-(A^-1)
E= (2+ (2*D))
DP3= ((D^2)/E)*DK
Z (F) =DP3
PRINT DP3
GOTO 60
50 PRINT "THREEDIFFERENT DIAMETER"
AM=DM/DG
A=DK/DG
K1= ((AM+1) ^2/ (AM-1)) ^2
K2= (4*AM)/ (AM+1)
K3= ((A^2+A*K2) ^ (1/2))-A
K4= (K2+ (2*K3))*K1
K5= (K3^2)*K1
DP4= (K4-((K4^2)-(4*K5)) ^ (1/2))*(DG/2)
Z (F) =DP4
PRINT " DP4="; DP4
60 PRINT "IF YOU WANT TO CONTINUE PRESS 0"
INPUT L
IF L<> 0 THEN 80
F=F+1
IF F<> 36 THEN 5
FOR I=1 TO 34
FOR J=1 TO 35-I
IF Z (J) <Z (J+1) THEN 70
T=Z (J): Z (J) =Z (J+1): Z (J+1) =T
70 NEXT: NEXT
FOR I=1 to 35
PRINT "Z ("; I ;") ="; Z (I)
NEXT I
80 INPUT "INTER 0 TO PRINT THE RESULTS "; H
IF H=0 THEN 90 ELSE GOTO 100
90 FOR I=1 to 35
```

```
PRINT " Z ("; I ;") ="; Z (I)
NEXT I
100 FOR I=1 TO 5
PRINT " ("; I ;") ="; N (I)
NEXT I
```

Program Number Two

```
REM **********************************************************
REM *****CALCULATING THE PROBABILITY OF PACKING *******
REM *****BED FOR FIVE DIAMETERS BY USING THEIR **********
REM **************NUMBER PERCENT *************************
REM *********R: TYPE OF DISTRIBUTION ***********************
REM **RK: TYPE OF DISTRIBUTION FOR SMALL PARTICALE******
REM **RM: TYPE OF DISTRIBUTION FOR MEDIUM PARTICALE ***
REM **********************************************************
CLS
FOR I=1 TO 5
PRINT " DIAMETER ("; I ;") = ";
READ N (I)
PRINT N (I)
NEXT I
DATA
D1=N (1):D2=N (2):D3=N (3):D4=N (4):D5=N (5)
PRINT "ENTER THE NUMBER PERCENT OF EACH DIAMETER"
FOR I=1 TO 5
PRINT " NUMBER PERCENT ("; I ;") = ";
READ P (I)
PRINT P (I)
NEXT I
DATA
FOR I=1 TO 35
10 PRINT "INPUT DIAMETER VALUE"
FOR I=1 TO 3
INPUT X (I)
NEXT I
FOR I=1 TO 2
FOR J=1 to 3-I
IF X (J) <X (J+1)   THEN 15
T=X (J): X (J): X (J) =X (J+1): X (J+1) =T
15 NEXT: NEXT
DK=X (1): DM=X (2): DG=X (3)
PRINT" ENTER NUMBER PERCENT FOR EACH CHOICE DIAMETER"
FOR I=1 to 3
INPUT E (I)
NEXT I
IF X(1)<>X(2) AND X(2)<>X(3) AND X(1)<>X(3) THEN RG=1:RM=1
```

```
: RK=1: GOTO 20
IF X(1)=X(2) AND X(2)=X(3) AND X(1) =X(3) THEN RG=3 :RM=0:RK=0
:GOTO 20
IF X(1)=X(2) AND X(1) <X(3) AND X(2)<X(3) THEN RG=1:RM=0:RK=2
:GOTO 20
IF X (3) =X (2) AND X (3)>X (1) THEN RG=2: RM=0: RK=1: GOTO 20
20 PRINT " RG="; RG: PRINT"RM="; RM: PRINT"RK="; RK
REM **CALCULATING THE FRACTIONAL OF RG, RM, RK *********
B (1) =RM: B (2) =RK: B (3) =RG
FOR I=1 TO 3
FACT =1
IF B (I) =0 THEN 30
FOR J=1 TO B (I)
FACT=FACT *J
NEXT
30 F (I) =FACT
PRINT "FACT ="; FACT
NEXT I
PRN=6*((E(1)^RK)*(E(2)^RM)*(E(3)^RG ))/(F(1)*F(2)*F(3))
K (J) =PRN
Z=Z+K (J)
L=(N(1)*P(1)+N(2)*P(2)+N(3)*P(3)+N(4)*P(4)+N(5)*P(5))
LK= (DK*E (1))/L
LM= (DM*E (2))/L
LG= (DG*E (3))/L
PRL=6*((LK^RK)*(LM^RM)*(LG^RG)/(F(1)*F(2)*F(3))
K(J)=PRL
T=T+K(J)
A=(P(1)*(N(1)^2))+(P(2)*(N(2)^2))+(P(3)*(N(3)^2))+(P(4)*(N(4)^2))+(P(5)
*(N(5)^2))
AK= (E (1)*(DK^2))/A
AM= (E (2)*(DM^2))/A
AG= (E (3)*(DG^2))/A
PRA=6*((AK^RK)*(AM^RM)*(AG^RG))/(F(1)*F(2)*F(3))
K (J) =PRA
Y=Y+K (J)
V=(P(1)*N(1)^3))+(P(2)*(N(2)^3))+(P(3)*(N(3)^3))+(P(4)*(N(4)^3))+(P(5)
*(N(5)^3))
VK= (E (1)*(DK^3))/V
VM= (E (2)*(DM^3))/V
VG= (E (3)*(DG^3))/V
```

```
PRV=6*((VK^RK)*(VM^RM)*(VG^RG))/ (F (1)*F (2)*F (3))
K (J) =PRV
W=W+PRV
PRINT TAB (1);" PRN"; PRN; TAB (20);"PRL="; PRL; TAB (40);"PRA=";
PRA; TAB (60);"PRV="; PRV
PRINT TAB (1);"Z"; Z; TAB (20);"T="; T; TAB (40);"Y=";
Y; TAB (60);"W="; W
NEXT I
INPUT U
IF U<> 36 THEN 10
FOR I=1 TO 35
FOR J=1 TO 35-I
IF K (J) <K (J+1) THEN 40
T=K (J): K (J) =K (J+1): K (J+1) =T
40 NEXT: NEXT
```

Program Number Three

```
REM********Calculating the mean pore diameter due to number *********
REM********Length, Surface area, and Volume ***********************
REM********dcn :the mean pore diameter due to number ***************
REM********dcl:the mean pore diameter due to  length*****************
REM********dca:the mean pore diameter due to surface area *************
REM********dcv: the mean pore diameter due to  volume***************
REM********dcmn: the mean pore diameter due to number***************
REM********dcml: the mean pore diameter due to  length***************
REM********dcma: the mean pore diameter due to surface area**********
REM********dcmv: the mean pore diameter due to  volume*************
CLS
FOR I=1 TO 35
INPUT" The diameter of the pores";dc.
INPUT" The Probability due to number";Prn
INPUT" The Probability due to length";Prl
INPUT" The Probability due to surface area ";Pra
INPUT" The Probability due to volume ";Prv
dcn=dc*Prn: Print "dcn=";dcn
dcl=dc*prl: Print "dcl=";dcl
dca=dc*pra: Print "dca=";dca
dcv=dc*prv: Print "dcv=";dcv
dcmn=dcmn+dcn:Print "dcmn=";dcmn
dcml=dcml+dcl:Print "dcml=";dcml
dcma=dcma+dca:Print "dcma=";dcma
dcmvl=dcmv+dcv:Print "dcmv=";dcmv
NEXT
END
```

الخلاصة

هدف البحث دراسة حجوم الفتحات والفراغية نظريا وعمليا وذلك لأهميتها في الابراج التي تحتوي على حشوات.

هناك أنواع مختلفة للتوزيع وهي:

1. التوزيع اللوغارتمي الطبيعي.
2. توزيعٌ RRSB.
3. توزيعٌ GGS.
4. توزيعٌ Rinkes.
5. توزيعٌ PM.

في هذا البحث استخدم توزيعٌ RRSB من اجل الحصول على النسبة العددية التي استخدمت في الحسابات النظرية واستخدمت أيضا في العملي.

$$H_3 = 1 - \exp\left[-\left(\frac{d}{d_{63/3}}\right)^n\right]$$

ولحساب حجوم الفتحات استخدمت طريقة نظرية (Latif equation) حيث استعملت خمس كرات مختلفة الأقطار (d1=6,d2=8,d3=10,d4=20,d5=26) ملم وضعت داخل اسطوانة قطرها 12.9 سم تحتوي على منخل فيه فتحات قطرها 4 ملم حيث تم إيجاد توزيعات إحصائية لأقطار الفتحات بالاعتماد على نسب مختلفة مثل النسب العددية والطولية والمساحية و الحجمية وتم عمليا حساب المسامية والنسبة الوزنية لثلاث انواع من الشوائب (A=1.2-2 , B=2-2.36, C=2.36-3)
ملم التي مررت خلال حشوة مكونة من كرات ذات خمس أقطار مختلفة عندما تكون الحشوة مكونة من طبقتين ثم ثلاثة وأربعةومن الملاحظ من النتائج العملية إن النسبة الوزنية للشوائب والمسامية تقل بزيادة عدد الطبقات وبزيادة جحم الشوائب.

وجدت علاقة بين النتائج العمليع والنظرية ادت الى ايجاد علاقة بين حجم الفتحة والنسبية الوزنية للشوائب والمسامية حيث وجد ان نسبة الشوائب والمسامية تزيد بزيادة حجم الفتحات وزيادة حجم الكرات المكونة للحشوة يزيد من حجم الفتحات.

أما بالنسبة للمسامية فقد حسبت بالنظام الأحادي نظريا بواسطة (Furnas equation) وحسبت عمليا بوضع عدد معين من الكرات في اسطوانة اولا 12.9 سم ثانيا 6.4 سم وقياس ارتفاع الكرات في الاسطوانة من اجل قياس الحجم الكلي وبمعرفة حجم الكرات نجد حجم الفراغ ثم نجد المسامية ومقارنة النتائج بالنتائج العملية ثم اشتقت معادلات جديدة .

1.بالاسطوانة ذات قطر9.12 سم نسبة الخطأ .% 2.59 & 0.3% المعادلات هي.

$$\varepsilon_f = 0.38017 + 0.3458\left(\frac{d}{D}\right) \quad ....(4.2)$$

$$\varepsilon_f = 0.3475 + 1.406\left(\frac{d}{D}\right) - 9.86\left(\frac{d}{D}\right)^2 + 27.11\left(\frac{d}{D}\right)^3 \quad ....(4.3)$$

2. بالاسطوانة ذات قطر 6.4 سم نسبة الخطأ % 4.16 & % 1.86 المعادلات هي.

$$\varepsilon_f = 0.38829 + 0.3319\left(\frac{d}{D}\right) ....(4.5)$$

$$\varepsilon_f = 0.33318 + 1.406\left(\frac{d}{D}\right) - 9.86\left(\frac{d}{D}\right)^2 + 27.11\left(\frac{d}{D}\right)^3 ....(4.6)$$

وحسبت فراغية النظام الثنائية نظريا بواسطة معادلتين(Jeschar and Latif equations) وعمليا بقياس ارتفاع خليط مكون من نوعين من الكرات (d1=26,d2=6) (d1=20,d2=6) ,(d1=10,d2=6),(d1=8,d2=6),(d1=26,d2=8),(d1=20,d2=8)(d1=10,d2=8), (d1=26,d2=10),(d1=20,d2=10),(d1=26,20) ملم في اسطوانة 12.9 سم لحساب الحجم الكلي ثم حساب المسامية ومقارنة نتائجهما بالنتائج العملية وتم اشتقاق معادلة جديدة بحسب الظروف العملية حيث تقل باستخدامها نسبة الخطأ حيث تصبح %13.8 &%0.04 المعادلة هي:

$$\varepsilon_f = \left(0.45488 + 0.05466 v_2\right)\left(\frac{d_2}{d_1}\right)^{0.1283 - 0.04068 v_2} ....(4.7)$$

شكر وتقدير

أود أن اعبر عن خالص شكري وتقديري وامتناني العميق للمشرف الدكتور محمد نصيف لما قدمه لي من توجيهات قيمة ونصائح سديدة طوال فترة أنجاز البحث.

أود أيضا أن اشكر أساتذة وموظفي قسم الهندسة الكيمياوية في جامعة النهرين لإبدائهم المساعدة اللازمة أثناء هذا العمل .

ولا أنسى أن أتقدم بالشكر والامتنان إلى من لازمني طوال فترة البحث وخلال أصعب الظروف الى اعز من في الوجود إلى أمي وأبي وأخوتي وأخواتي فلهم جزيل الشكر.

قياس حجوم الفتحات والمسامية في الحشوة
باستخدام توزيع RRSB

رسالة
مقدمة الى كلية الهندسة في جامعة النهرين
وهي جزء من متطلبات نيل ماجستير
علوم في الهندسة الكيمياوية

من قبل
سهى مهدي صالح
(بكالوريوس علوم في الهندسة الكيمياوية٢٠٠٣)

جمادى الأول ١٤٢٧
حزيران ٢٠٠٦