Prediction of Pore Size in Packed Bed consisting of Four Sizes of Glass spheres

A Thesis

Submitted to the College of Engineering of

Al-Nahrain University in Partial Fulfillment of the

Requirements for the Degree of Master of Science in

Chemical Engineering

By

Yousra Saber Kareem Al-Khoshnao

(B.Sc. in Chemical Engineering 2002)

Rabee al-awal	**1426**
April	**2005**

CERTIFICATION

We certify that the preparation of this thesis titled "***Prediction of Pore Size in Packed Bed Consisting of Four Sizes of Glass Spheres***" was made by **Yousra Saber Kareem Al-Khoshnao** under our supervision at Al-Nahrain University, College of Engineering, in partial fulfillment of the requirement for the degree of Master of Science in Chemical engineering.

Signature:

Dr.Mohammed .N. Latif

Date :22/ 5 /2005

Signature:

Prof.Dr.Qasim J.Slaiman

Head of Chemical Engineering Department

Date :24/ 5 / 2005

CERTIFICATE

We certify, as an examining committee, that we have read the thesis entitled "***Prediction of Pore Size in Packed Bed Consisting of Four Sizes of Glass Spheres***" and examined the student **Yousra Saber Kareem Al-Khoshnao** in its content and found it meets the standard of thesis for the degree of Master of Science in Chemical Engineering.

Signature:
Dr. Mohammed.N.Latif
(Supervisor)
Date :22/5/2005

Signature: C. Kh. Haweel
Dr. Cecilia.K.Haweel
(Member)
Date : 23/5/2005

Signature:
Dr. Talib.B.Kashmoula
(Member)
Date : / /

Signature: J. Shanshool
Prof.Dr.Jabir Shanshool
(Chairman)
Date :22/5/05

Approval of the College of Engineering.

Signature:
Prof. Dr. Fawzi M. AL-Naima
Dean of the College of Engineering
Date 1/6/2005

Abstract

Packed beds are used in many process industries (**e.g.** Adsorption, Absorption, Distillation, and Filtration).

This research involved the study of packed bed properties and tests it in theoretical and experimental methods.

The packing consist of four sizes of glass spheres and their diameters are: d1=10.6mm, d2=14.97mm, d3=20.89m, d4=25.84mm.

The theoretical method was given by Latif involve evaluating the diameter of the pores, mean pore diameter, and the probability due to number, surface area, length, and volume .the results obtained using software programs (Q.BASIC, EXCEL) and these results shows that the probability of finding pore size is different for each distributions.

The experimental work was by making a packed bed with different composition and layers but the same diameters used in theoretical methods and weigh the impurities before entering the packed bed and after leaving it to find the percent output .Three sizes of impurities were used and its diameters are: 1.2-3.3mm, 4.2mm, and 6mm.

Results obtained from the experimental work showed that the percent output of impurities decreased with increasing the number of layers; and also decreased with increasing the size of impurities for each value of number percent of spheres. Experimental results related with the theoretical results in order to find the relation between mean pore diameter and percent output of impurities for each bed.

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List of Symbols

Symbol	Definition	Unit
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.	
d	Particle diameter.	mm
dc	Diameter of the pores.	mm
dc_1	Pore diameter of three different sizes of diameter.	mm
dc_2	Pore diameter of two equal and one different size of diameter.	mm
dc_3	Pore diameter of three equal sizes of diameter.	mm
dc_m	Mean pore diameter	mm
dc_ma	Mean pore diameter due to area.	mm
dc_ml	Mean pore diameter due to length.	mm
dc_mn	Mean pore diameter due to number.	mm
dc_mv	Mean pore diameter due to volume.	mm
d_g	Large particle diameter.	mm
d_K	Small particle diameter.	mm
d_m	Medium particle diameter.	mm
K_1 to K_5	constants	
L_g	Length function of large spheres.	
L_k	Length function of small spheres.	
L_m	Length function of medium spheres.	
n	Number of repetition.	

$\mathbf{n_g}$	Number of repetitions for large particles.
$\mathbf{n_K}$	Number of repetitions for small particles.
$\mathbf{n_m}$	Number of repetitions for medium particles.
$\mathbf{N_g}$	Number function of large spheres.
$\mathbf{N_k}$	Number function of small spheres.
$\mathbf{N_m}$	Number function of medium spheres.
$\mathbf{P_i}$	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.
$\mathbf{r}$	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.
$\mathbf{V_g}$	Volume function of large spheres.
$\mathbf{V_k}$	Volume function of small spheres.
$\mathbf{V_m}$	Volume function of medium spheres.

Chapter One
Introduction

1.1. Introduction

Many materials (ex. soil, sand, packed catalyst bed) consist of a large number of particles or fibers packed bed closely together .In between the solid particles or fibers there is open space called "pores"[1].

Pores are void spaces which must be distributed less frequently through the material if the latter is to be called "porous". Extremely small voids in a solid are called "molecular interstices", very large ones are called "Caverns". "porous" are void space intermediate between caverns and molecular interstices; the limitation of their size is therefore intuitive and rather indefinite [2].

A packing of particles is an assemblage of particles and is widely encountered in many industries. Pore size is known to be the simplest and most accessible parameter in characterizing particle packing. Particle characteristics affect porosity mainly via three factors:

- Dimensionless particle size distribution.
- Particle shape.
- Absolute particle size.

Giving various packing systems from the simplest spherical particle packing to the complicated system involving fine and non- spherical powders [3].

Porous materials occur in great variety, both in nature and industry .living organisms are all Porous; their life functions would not be possible without porous in them .pores make breathing possible as well as the circulation of natural fluids in both plant and animal life [4].

In the inanimate world porous structures are just as widespread and important. Soil is porous and so are most natural rocks, to a varying degree. Graphite, mica, sand stone, and limestone, fibrous aggregates such as cloth, felt, filter paper, and catalytic particles containing extremely fine micro pores are just a few examples [4].

Ground water, petroleum, and natural gas are among the important substances that are contained in the pore spaces provided by various geological functions. Among industrial products, porous materials are again numerous and of great practical value. Materials of construction such as ceramics, concrete, and timber are porous [4].

In addition, porous materials play an important role in many process industries as adsorbents, such as silica gel, active charcoal, zeolites-molecular sieves, a large variety of contact catalysts, and filters. Electrodes in batteries and electrolysis plants are often porous. Many commercials products are granular or porous, and technology of drying such as materials has to consider their porous nature. The pore structure of ores is important in process metallurgy [4].

The variety of porous materials and their spherical significance, along with the shapes, sizes, and nature of the pores is so great, that no comprehensive treatment of the pore structure analysis has ever been attempted [4].

The pores in a porous system may be interconnected or none interconnected. Flow of interstitial fluid is possible only if at least part of the pore space is interconnected. The interconnected part of the pore system is called the effective pore space of the porous medium [2].

Pore spaces have been divided according to whether they are ordered, or disordered; and also according to whether they are dispersed (as in beds of particles) or connected [2].

Pore space models are used to obtain values for the transport coefficient (effective diffusion coefficient permeability) and –when applicable – the driving force (capillary potential) in the transport equation. These models and this approach have to be distinguished from:-

- ❖ Models used in simulating particle packing.
- ❖ Models used in determining the so-called pore size distribution (suction technique, mercury porosimetry).
- ❖ Analytic calculation of the transport coefficient.
- ❖ Overall description of the transport phenomena. (In which the microscopic pore space structure is not accounted for.) [5].

In this research we will give a description of pores using spherical particles which will pass through expected pores, and evaluate the probability of the pore diameter due to volume, surface area, number, and length and relate the experimental results with the theoretical method for calculation.

Chapter Two

Literature Survey

2.1. Descriptions and Physical Properties of Porous Media

Transport in heterogeneous and disordered media has important applications in many fields of science including composite materials, rheology, geophysics, polymer physics, statistical physics, chemical physics, colloid science, petroleum exploration and technology, and biotechnology. Progress in the field of heterogeneous media was, until recently, hampered by the difficulties involved in characterizing the complex random microstructure. The problem consists in characterizing the microstructures quantitatively in such a way that the characterization can be used to predict physical transport quantities such as permeability, conductivity or elastic constants [6].

A general and unified methodology was developed to characterize disordered heterogeneous materials quantitatively. This methodology was given the name local porosity theory because it focuses on local fluctuations of porosity and other geometrical descriptors. It allows a quantitative transition from microscopic to macroscopic scales in porous media [6].

A particularly important subclass of disordered heterogeneous materials is porous media. For porous media, the prediction of multiphase fluid flow has remained largely impossible despite many years of research in academia and industry. Solutions to this problem would be of great importance for many applications **(e.g.** prediction of groundwater flow, chemical reactions in catalysts, and flow through gels, granular media, textiles, constructions materials, filtration technology, hydrocarbon production or in situ remediation of contamination areas)[7, 8, 9, 10].

A porous medium consists of a connected 3-dimensional solid matrix with a highly ramified network of pores and pore throats in which fluids may flow. Porous media are often characterized in terms of "pore size distributions" but this does not provide a sufficient description for the calculation of important physical properties such as permeability [11].

A variety of models for the pore space geometry of porous media have been developed. However, simple models that can be used to calculate macroscopic physical properties have not been developed [11].

A considerable effort has been invested in making transparent models of porous media by using transparent solid materials for the matrix and fluids of the same index of refraction. Vidar Frette has been a driving force in the development of the three-dimensional transparent models and has used the technique to study many interesting interface-structures arising in two-fluid displacement in three-dimensional experiments [11].

2.2. Theory of Packing of Spheres and Natural Materials

In order to establish a correlation between grain size and pore size of an unconsolidated porous medium, one has to know something about the packing of the grains as well as about their shape [12].

For even the size of the grain (**i.e.** the largest diameter) is known, the shape is still not determined. The grains that pass through a certain sieve-mash and do not pass through another slightly smaller one are not necessarily all identical, owing to the irregularity of shape [12].

The first study of the models of packing of spheres and the porosity calculated therefore appears to have been under taken by Slickter (1899).since then the theory has been reviewed, refined, and extended by Smith, Foote and Busang (1929), Graton and Fraser (1935) fig.2.1, Manegold (1937), Manegold and Solf (1939), Hrubisek (1941), and others sited in [13, 14].

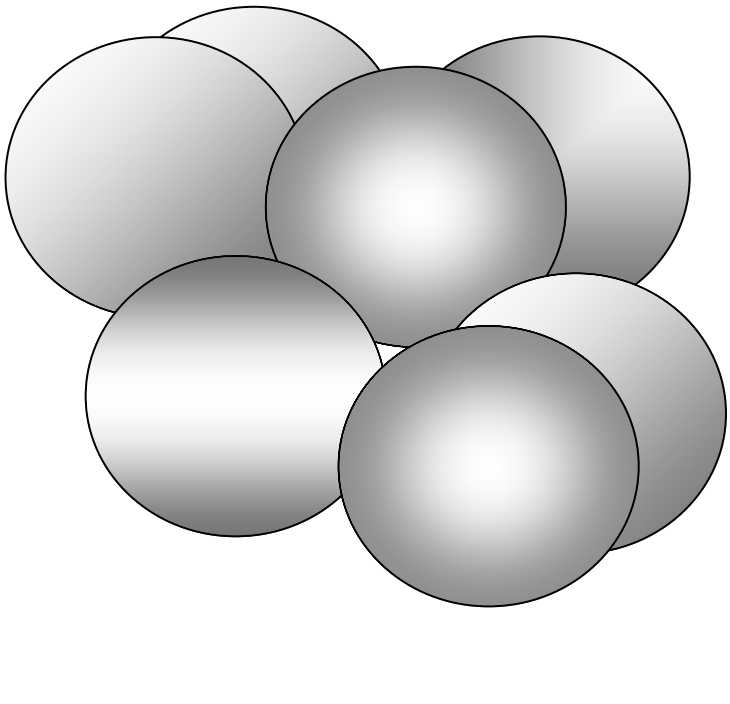


Fig.2.1. Rhombohedral packing of spheres.

Natural materials are composed of grains whose shape may deviate appreciably from that of spheres. Moreover, it will often be found that the grains are somewhat cemented together without being fully consolidated, but it would still be desirable to apply some correlations between " grain size" and pore size distribution and other characteristics of the porous medium, such as specific area. Furthermore, the size of the grains will seldom be very uniform. Non-uniformity in size will, in general, permit the smaller particles to fill the spaces between the larger ones and thus appreciably reduce porosity. Contrariwise, angularity of the particles permits bridging with a resulting increase of porosity [15, 16, 17].

Theoretical and experimental studies of the effect of grain size on pore size have been conducted by Tickell, Mechem and McCurdy (1933), Nissan (1938), Cloud (1941), Rosenfeld (1949), Griffiths (1952), and Gaither (1953) sited in [18, 19, 20, 21].

2.3. Pore Size, Shape and Distribution

There are three basic pore models exist: [22]

1. Cylindrical pores, circular in cross section.
2. Ink-bottle pores having a narrow neck and wide body.
3. Slit-shaped pores with parallel plates.

Pore size distribution is the secondary parameter. This could be measured by the method of mercury porosimetry [22].

Mercury porosimetry method is most widely used in the measurement of pore-size distribution. In the mercury intrusion porosimetry method, a cylindrical pore model is assumed, and the size of pores is principally calculated using the Washburn equation:

$$D=14(\cos\alpha/p)$$

Where D is the apparent diameter of the pore being intruded, α is the contact angle between mercury and the material, and P is the absolute pressure causing the intrusion. This equation can be used to convert pressure to pore diameter. The pore-size distribution can be determined by measuring the volume of mercury intruded into the pores as a function of pressure [23].

More direct methods using the principles of X-ray scattering have been employed (Brusset, 1948; Ritter and Erich, 1948; Shull, Elkin and Roess, 1948; Avgul etal. 1951; Clark and Liu, 1957) [2].

Another method is to break down porous medium by crashing it more and more finely. At each stage of crushing the porosity can be measured, which turns permits evaluation of the pore size distribution as the larger pores, are progressively destroyed (Gilchrist and Taylor, 1951) [2].

But the most modern technique to measure pore size distribution is the TRI/Autoporosimeter.

The TRI/Autoporosimeter is a unique, computer-controlled, precision instrument with user-friendly hardware and software. It measures pore size distribution, pore volume distribution, and numerous other characteristics of porous materials in the pore radii range of 1 to 1,000 microns in a non-destructive manner [24].

2.4. Pore Size Measurement using new NIST Traceable Micro Sphere Standards

Pore size measurement has been traditionally performed by the Bubble Point measurement where by the maximum aperture size present can be related to the pressure at which a bubble appears on the top side of a wetted filter medium pressurized [25].

An alternative method is the so-called 'Challenge test'. In this method standard test dusts or glass beads are presented to a filter medium and the size distribution in the downstream flow analyzed. This method gives a more absolute measurement of pore size because it measures real particles but, because the size distributions involved are often broad, there is a significant uncertainty in the measurement of the largest particles passing the filter medium [26].

Particle shape can also affect the penetration of the filter media by the challenging particles, irregular particles tending to lock into the tortuous pathways through the filter media. A simple example is the comparison of spheres and discs passing various filter media, figure 2.2. The optimum particles for a challenge test are therefore spherical, narrow size distribution micro spheres [27].

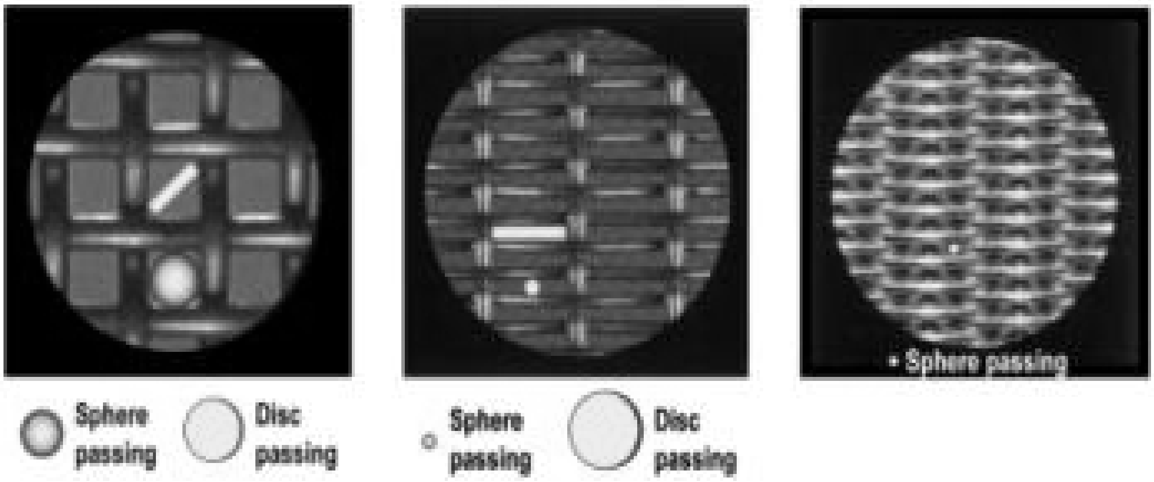


Fig. 2.2. **Particle shape and aperture shape affect filter efficiency**

The complex structures produced from the latest weaving technology make traditional testing methods such bubble point measurements and challenge test methods less reliable. Potential users of filter media are therefore demanding more accurate methods of filter pore size measurement and this requires a different approach and technical understanding of filtration efficiency. It will describe the preparation and use of narrow particle size distribution glass micro sphere standards in measuring the pore sizes of some of the latest high performance filter media [28, 29].

2.4.1Pore size measurement by using sonic shifting:-

Measuring the pore size of micro spheres effectively through the often tortuous path in the complex filter structure is difficult .This problem has been solved by using a Sonic sifting device that fluidizes the micro spheres rather than shake the filter as in traditional sieve shakers. The pore size measured is approximately 97% of the maximum particle passing the medium when measured by microscopy, or effectively cut point or retention quality of the filter medium [29].

2.4.2 Pore size measurement using an ultrasonic wet system:-

Although the Gilson Sonic shifter can measure particles on an Electroformed sieve down to 5mm, the restricted flow through filter media of a similar pore size makes fluidization almost impossible and a wet, ultrasonic method must be used. The apparatus employed was a simple split filter holder on a Buchner flask, an ultrasonically dispersed dilute suspension of an appropriate filter standard was then drawn through the filter under test by vacuum. The particle size before and after filtration was analyzed by microscope and image analysis [29].

2.5. Applications to Seperation [30]

2.5.1 Description of Elementary Mechanisms

Consider the inventory of all parameter which describes the elementary process of clogging and décolletage, i.e., the retention sites fig.2.3, the retention force exerted on the particles retained in these sites, the capture mechanisms which bring the particles into contact with the sites, as well as the décolletage processes of retained particles.

- **Constriction sites**: the particle can not penetrate into pore of smaller size than its own.

- **Retention sites:** it is possible to distinguish several retention sites.

- **Surface sites:** the particles stops and is retained on the surface of porous bed grain.

- **Crevice sites:** the particle becomes wedged between the two convex surfaces of two grains.

- **Cavern sites:** the particle is retained in a sheltered area, a small packed formed by several grains.

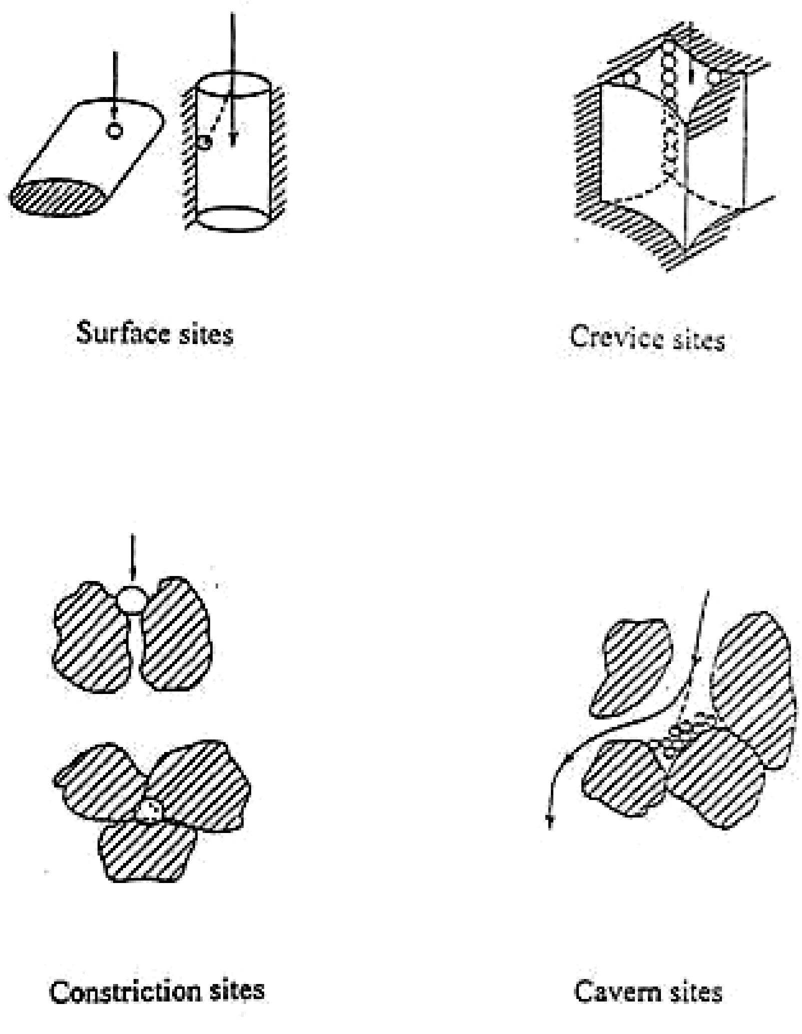


Fig. 2.3. Several retention sites

2.5.2 Retention Force

They include:

- **Friction Force:** A particle wedged in a crevice may have been slightly deformed then when stopped, and may remain in place by friction.

- **Surface Forces:** these include the Van deer Val forces, which are always attractive, and the electrical forces (electrostatic or electro kinetic) which are either attractive or repulsive according to the physiochemical conditions of the suspension.

- **Chemical forces:** in the case of colloidal particles or other particular cases actual chemical bonding may occur.

2.5.3 Capture Processes

These are:

- **Sedimentation:** if the particle have a density different from that liquid, they are subjected to gravity and their velocity no longer is that of the fluid, thus by sedimentation they can meet the filter medium.

- **Inertia:** still owing to their apparent weight, the particles can not follow the same trajectories as the fluid, they deviate from the stream lines (when the directions of the trajectories change suddenly) and can be brought into contact with the bed grains.

- **Hydrodynamic effect:** owing to the non-uniform shear fluid and the non-sphericity of particular, hydrodynamic effect may occur; these effects cause a lateral migration of suspended particles which may be brought into contact in this way with retention sites.

- **Direct interception:** even with exactly the same density as the fluid, the particles would not be able, owing to their size, to follow the smallest tortuosities of the streamline of the carrier fluid and they will thus collide with the walls of the convergent areas of the pores.

- **Diffusion by Brownian motion**: the particles diffuse and can reach areas which are not normally irrigated by the suspension, and they are retained there.

2.5.4 Decollitage Processes

It is necessary to distinguish between the spontaneous Décolletage due to the normal flow of suspension through the clogged bed, and the Décolletage caused by the operator who suddenly changes the flow conditions.

Spontaneous décolletage may occur if local variations in pressure or flow rate change the flow in the neighborhood of retained particles or if moving particles collides with retained particles.

Provoked décolletage results from impulses i.e. from sudden variations in pressure or flow rate in the whole bed caused by the operator or by reversal of the flow direction.

The processes of spontaneous or provoked décolletage are similar, but the extent of the first is local, whereas the second occurs every where in the whole bed.

2.5.5 Significance of Direct Interception

Even if particles have the same density as fluid, they meet the filter medium when streamlines they follow become nearer than d/2 for the grain surfaces; this process occurs in the constrictions and flow-past obstacles fig. 2.4. The particles brought into contact with the filter medium will stop if there are some available retention sites.

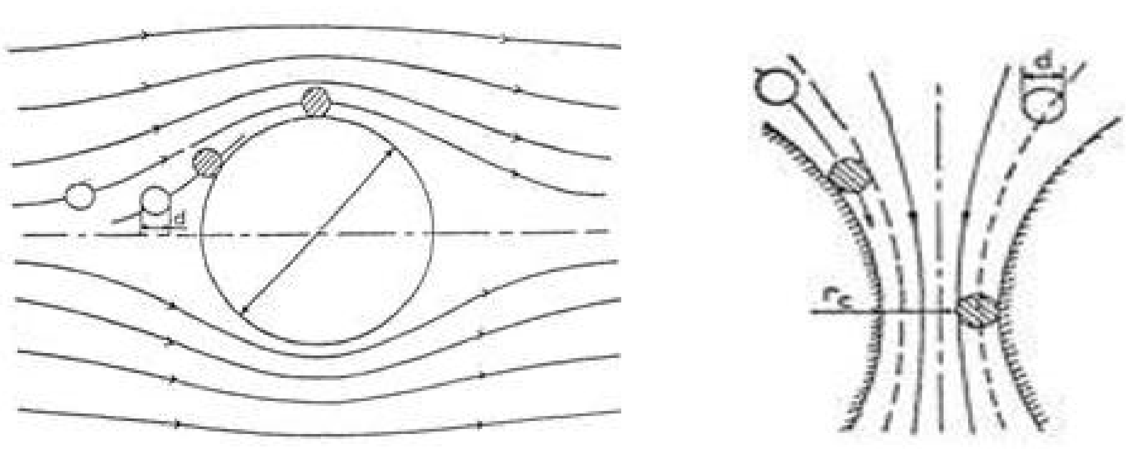


Fig. 2.4. Direct interception.

2.5.6 Elementary Mechanisms

Retention sites according to delachambre and sakthivadivel; particles follow the streamlines but are stopped in the passageways to narrow for passage (crevices and constriction).the resulting deposits continuously reduced the free passage and eventually causes blocking and filling up of settle by gravity on the grain tops on the horizontal pore services and thus narrow or block the channels[31].

The various studies about flow of suspension through porous media allow the following conclusions:

1. The possible elementary mechanism of deep filtration is known and they could be brought in evidence. However, it is always difficult to evaluate accurately their significance in any system. Therefore, experimental studies are needed before any filtration.

2. Two theoretical filtration types may be defined:

- A mechanical deep filtration for large particles (over30 μ); for them, volume phenomena prevail and spontaneous décolletage is improbable.
- A physiochemical deep filtration for small particles (approx.1 μ); for them, surface effects prevail and spontaneous décolletage may occur in case of sudden variations of flow rate or pressure.
- Typical deep filtration is performed for mean particles of intermediary size; thus, volume phenomena and surface effects have the same order of magnitude.

3. The fluid pressure drop through the porous medium increase with retention [31].

Table 2.1 Experimental Conditions of Some Investigations

Author	Particles		Porous Medium		Liquid	Filtration Rate (cm/s)	Flow	Flocculant or irons
	Type	Size(μ)	Type	Size(μ)				
Sakthivadivel	Styron	900-1400	Spherical Plastic balls	12500	Mineral oil	0.1-0.4	laminar	none
Moroudas	Spherical poly-Styrene	125-390	Model filter	Channels> 3000	water	0.06-30	Laminar and transition	none
	Angular quartz	<50	Packed bed (glass spheres)	2000				
delachambre	Spherical poly-styrene	60-350	Glass rods Glass spheres	3300 2280-3600	Organic mixture		Turbulent and transition	none
leclerc	pollen	32	Glass spheres	500-1000	Organic mixture	0.05-2.0	laminar	none
Herzig	pollen	31	Glass spheres	500	Organic mixture	0.02-0.1	laminar	none
Edwards-Monke	clay	1	sand	350	water	0.007	laminar	ions
Heertijes-lerk	Iron hydroxide	0.1-10	Glass spheres	540,650,780	water	0.14-0.3	laminar	flocculants
Ives	Polyvinyl-chloride	1.3	Glass spheres , anthractie	425-1100	water	0.06-0.2	laminar	ions
jorden	clay	1	gravel	5500	water	0.007	laminar	ions
o·melia stumm	Ferric precipitate		Glass spheres	4000	water	0.18	laminar	ions
Trzaska	clay	2	Glass spheres	800,1300	water	0.007-0.025	laminar	
Borchardt,o·melia	algae	15-60	sand	320,400,525	water	0.01-0.14	laminar	
Cleasby-baumann	Hydrous ferric-oxide,calcium carbonate	5 1-10	sand	500	water	0.07-0.7	laminar	flocculants
Eliassen	Ferric hydroxide	6-20	sand	460	water	0.14	laminar	flocculants
Fox-cleasby	Ferric hydroxide	4-25	sand	700	water	0.2-0.4	laminar	flocculants
Ghosh	diatomite	20	Sand, glass spheres	460,650,770	water	0.07-0.2	laminar	None
Herzig	Almunia,silica	4	Glass spheres	500	water	0.05-0.3	laminar	None
hsiung	Ferric hydroxide		sand	386,458,545, 649,771	water	0.4-0.8	laminar	flocculants
Ives	algae	4x10,5	Sand, glass spheres, anthracite	250-1300	water	0.05-0.25	laminar	Flocculants
	kaolinite	2.5-10						
iwasaki	Algae,clay	1-40	sand	100-800	water	0.0035-0.012	laminar	None
krone	bacteria	1x4	sand	63,190,400	water	0.01-0.20	laminar	None
ling	diatomite	10	sand	350-550	water	0.07-0.40	laminar	Flocculants
Mackrle	ferric hydroxide	5-20	Sand, anthracite	900-1750	water	0.10-0.400	laminar	Flocculants
Mintz	Clay, humus		sand	1000-2150	water	0.15-0.25	laminar	Flocculants
o·melia-crapps	ferric hydroxide	20	sand	700	water	0.14	laminar	Flocculants,i-ons
ornatskii	clay		sand					
stanfordgates	Bacteria, alum floc	>10	sand	500	water	0.14	laminar	Flocculants
shekhtman	Cravon paste	<10	sand	800-1200				
smith	clay	5	sand	600	water	0.14	laminar	Flocculants,i-ons

2.6. Models and Equations for the Calculation of Pore Diameter

There are three models which are based on an experimentally accessible quantitative characterization the pore space geometry [5].

One-dimensional models entail that transport is possible in one direction only as in Fig. 2.5; two dimensional models permit transport in a plane containing the microscopic transport direction as in Fig 2.6 and, three dimensional models permit transport also in plane perpendicular on the microscopic transport direction as in Fig. 2.7[5].

Packing of the packed bed which will represent the pore medium, and impurities have been represented as spherical particles by Latif (1981) as shown in fig.2.8. [32]

A mathematical procedure will be use which helps to study the motion of impurities, and packed bed particles is suggested. In this work we use the same procedure to find the pore size of a packed bed consisting of spheres and impurities as small spherical particles.

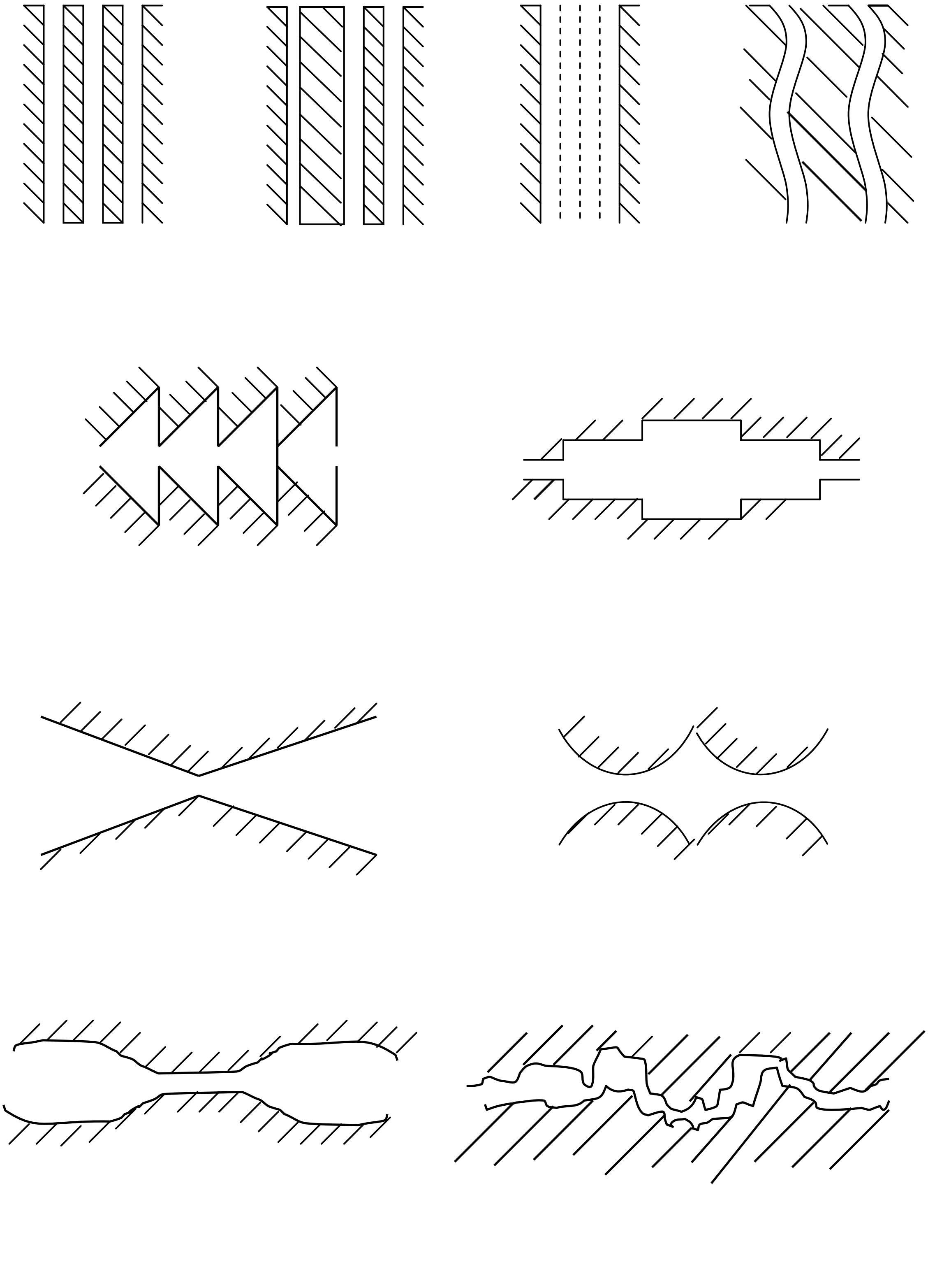


Fig. 2.5. Elements of pore space models with

One-dimensional connectivity

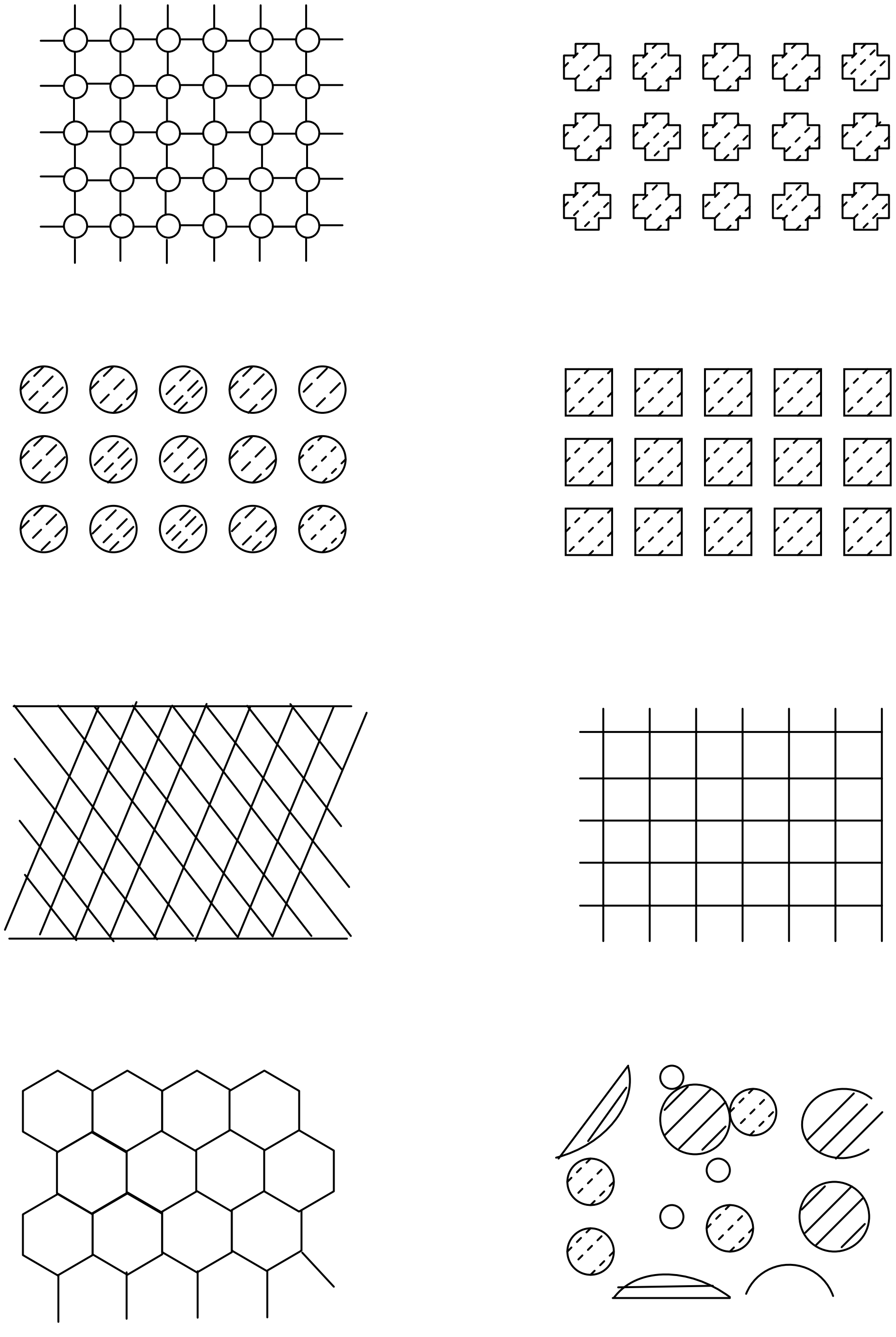


Fig.2.6. Elements of pore space models with Two- dimensional connectivity

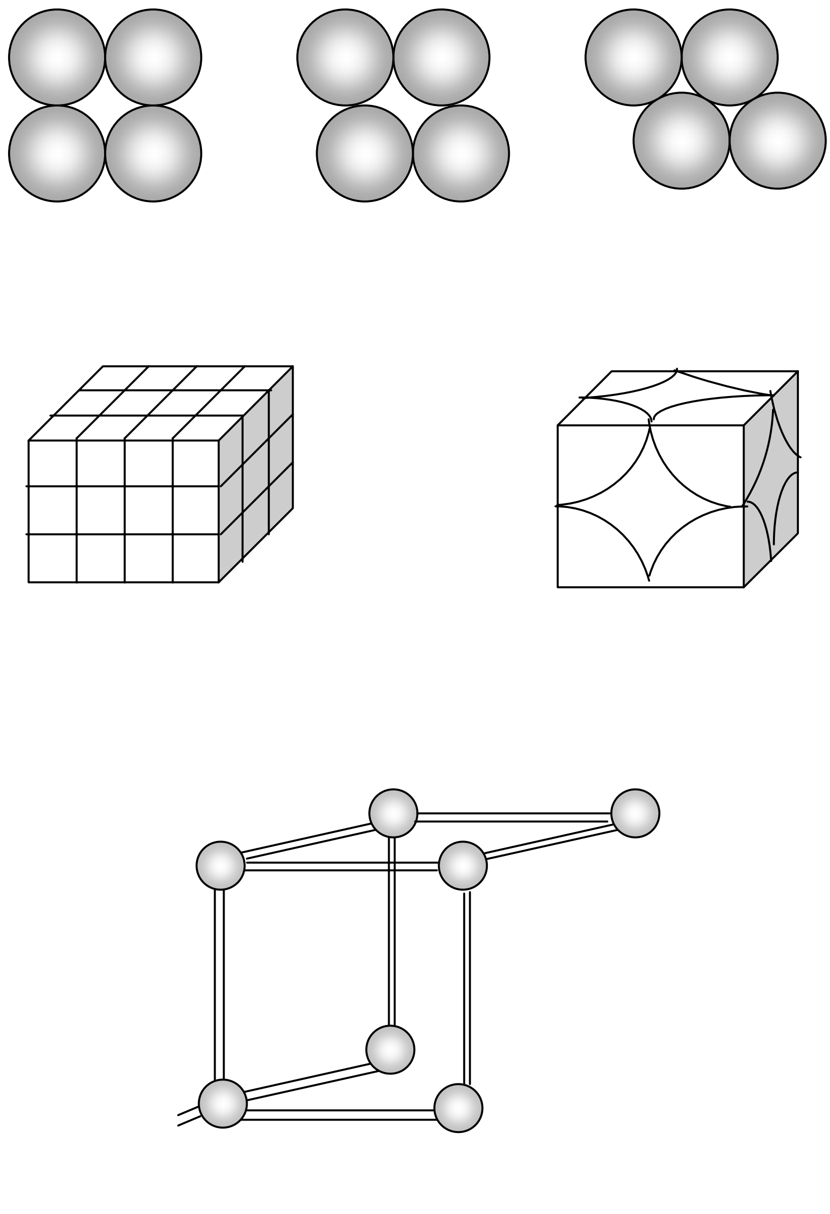


Fig. 2.7. Elements of pore space models with Three-dimensional connectivity

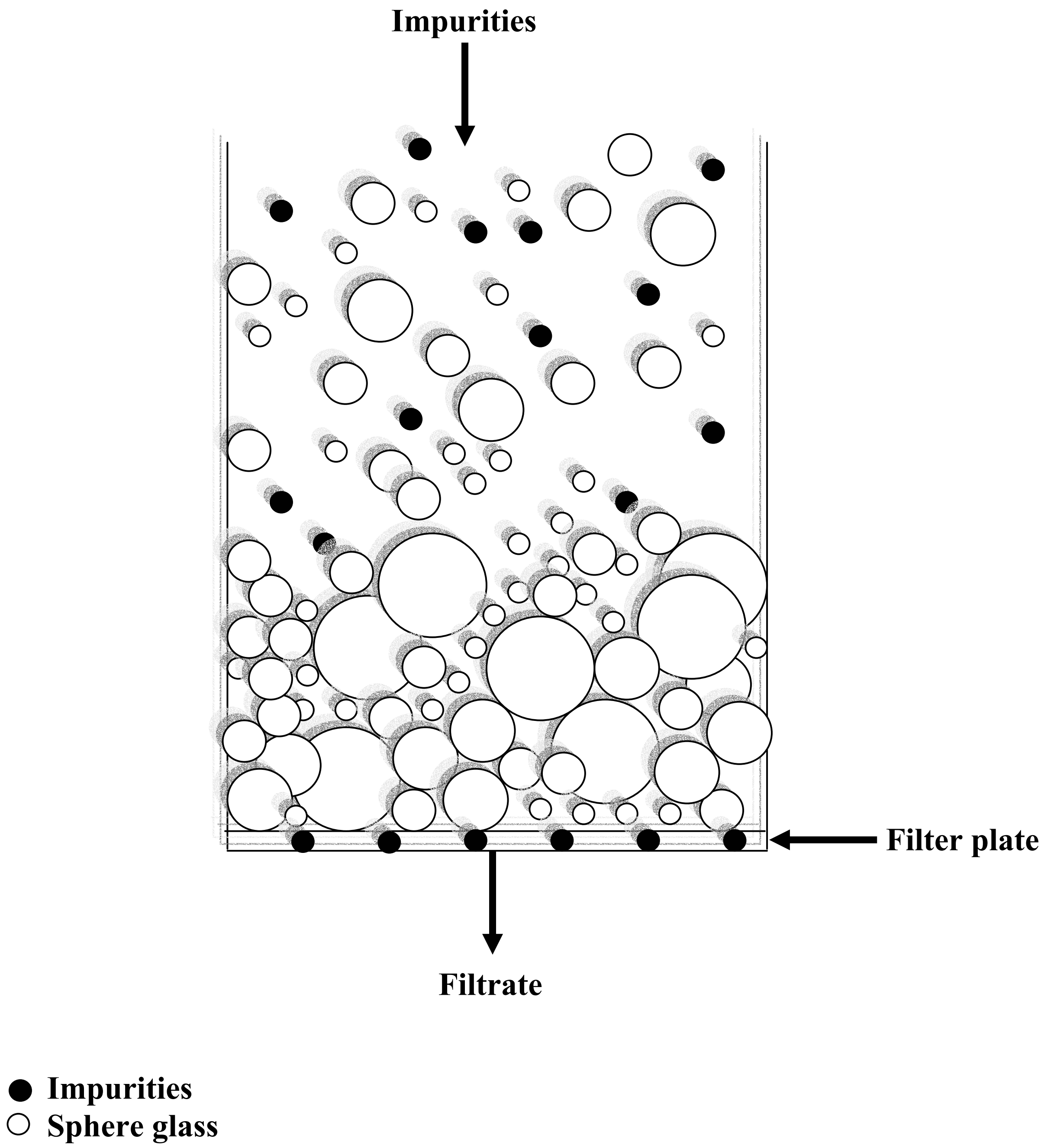


Fig. 2.8. Filter Aids model

The calculation procedure is as follows:

1. The diameter of the spheres ($d_{C\,1}$) which may be able to pass through the pore, as shown in Fig.2.9.1, which represent the general case [32].

$$d_{C1} = \frac{k_4 - (k_4^{\,2} - 4k_5)^{0.5}}{2} \times d_g \qquad \cdots 2.1$$

Where:

$$k_1 = \left[\frac{(a_m + 1)}{(a_m - 1)}\right]^2 \qquad\qquad k_2 = \frac{4a_m}{(a_m + 1)}$$

$$k_3 = \left(a_k^{\,2} + a_k k_2\right)^{0.5} - a_k \qquad\qquad k_4 = \left(k_2 + 2k_3\right) \times k_1$$

$$k_5 = k_3^{\,2} \times k_1$$

$$a_k = \frac{d_k}{d_g} \quad (<= 1) \qquad\qquad a_m = \frac{d_m}{d_g} \quad (= 1)$$

2. The diameter ($d_{C\,2}$) as shown in Fig. 2.9.2 and 2.9.3 may be calculated by equation 2.2.a and equation 2.2.b for case a and b respectively [32].

$$d_{C2} = \frac{[(2a_k + a_k{}^2)^{0.5} - a_k]^2}{2 + 2[(2a_k + a_k{}^2)^{0.5} - a_k]} \times d_g \qquad \cdots 2.2a$$

$$d_{C2} = \frac{[(2/a_k + a_k{}^{-2})^{0.5} - a_k{}^{-1}]^2}{2 + 2[(2/a_k + a_k{}^{-1})^{0.5} - a_k{}^{-1}]} \times d_k \qquad \cdots 2.2b$$

Where:

$$a_k = \frac{d_k}{d_g}$$

3. The diameter ($d_{C\,3}$) can be calculated by the equation written below when dk=dm=dg we have, see Fig. 2.9.4.[32]

$$d_{C3} = 0.155 \times dg \qquad \cdots 2.3$$

Then the probability that the diameter dc will occur is:

$$p_i = \frac{3!}{n_g!n_m!n_k!} p_{r_{dg}}{}^{ng} \times p_{r_{dm}}{}^{nm} \times p_{r_{dk}}{}^{nk} \qquad \cdots 2.4$$

The mean pore diameter dc_m then calculated by the following equation:[32]

$$dc_m = \sum_{i=1}^{n} p_i dc_i \qquad \cdots 2.5$$

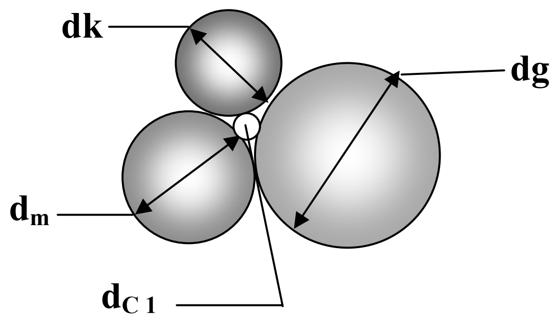


Fig. 2.9.1
General case

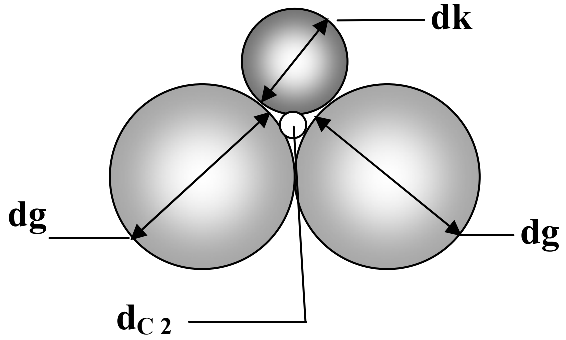


Fig. 2.9.2 pore by two different spheres Diameters dg=dg>dk

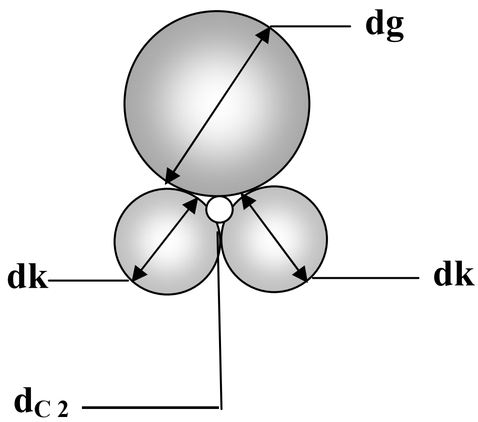


Fig. 2.9.3 pore by two Different spheres Diameters ds=ds>dl

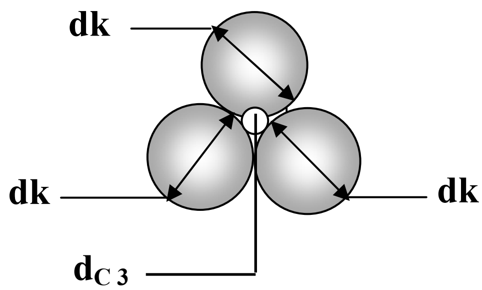


Fig.2.9.4 pore by three equal spheres diameters

The calculation of the pore diameter (dc) is based on the distribution of the four sizes of spheres and according to their arrangement the equations in above. The calculations of the probabilities are based on the number percent of each type of spheres and the other probabilities will be obtained from it as in the following equations:

- **Probability due to length…[32]**

$$L = (d_1 \times N_1) + (d_2 \times N_2) + (d_3 \times N_3) + (d_4 \times N_4) \qquad \cdots 2.6$$

$$L_1 = \frac{(d_1 \times N_1)}{L} \qquad L_2 = \frac{(d_2 \times N_2)}{L}$$

$$L_3 = \frac{(d_3 \times N_3)}{L} \qquad L_4 = \frac{(d_4 \times N_4)}{L}$$

- **Probability due to area…[32]**

$$A = (d_1^{\,2} \times N_1) + (d_2^{\,2} \times N_2) + (d_3^{\,2} \times N_3) + (d_4^{\,2} \times N_4) \qquad \cdots 2.7$$

$$A_1 = \frac{(d_1^{\,2} \times N_1)}{A} \qquad A_2 = \frac{(d_2^{\,2} \times N_2)}{A}$$

$$A_3 = \frac{(d_3^{\,2} \times N_3)}{A} \qquad A_4 = \frac{(d_4^{\,2} \times N_4)}{A}$$

• **Probability due to volume…[32]**

$$V = (d_1^{\,3} \times N_1) + (d_2^{\,3} \times N_2) + (d_3^{\,3} \times N_3) + (d_4^{\,3} \times N_4) \qquad \cdots 2.8$$

$$V_1 = \frac{(d_1^{\,3} \times N_1)}{V} \qquad V_2 = \frac{(d_2^{\,3} \times N_2)}{V}$$

$$V_3 = \frac{(d_3^{\,3} \times N_3)}{V} \qquad V_4 = \frac{(d_4^{\,3} \times N_4)}{V}$$

The diameters used in the calculations of the pore diameter (dc) are:

D1=10.6mm.

D2=14.97mm.

D3=20.89mm.

D4=25.84mm.

Chapter Three
Experimental Work

3.1 Materials and Tools

The experimental work was done by using the main system which is consists of many instruments:-

1. Graduated glass cylinder with height 16.5 cm, diameter 13 cm, knowing that this cylinder is opened from the top and bottom.

2. The sieve, which represents the filter plate, that the cylinder will be put on it.

   This sieve is used to retain the spheres that the packed bed consist of, and has square pores with diameters 1.1*1.1 cm .It is connected to the cylinder by a resin material mixed with black cascade maker. This system and its parts are shown in the Fig.3.1.

3. A digital balance (for high accuracy) was used to weight the mass of the input and output material from the packed bed.

4. Four sizes of glass spheres were used as the packed beds. Details of these spheres are given in Table 3.1.

Table 3.1 Diameters of glass spheres

Diameter (mm)	symbol
10.6	1
14.97	2
20.89	3
25.84	4

5. To represent the impurities separated by the packed bed, many types of spheres were used. These impurities are listed with their diameter and weight in Table 3.2.

Table 3.2 impurities weights and diameters

Diameter of impurities (mm)	Symbol of mixture	Weight (gm)	Number of impurities
1.2-3.3 (glass)	A	50	322
4.2 (lead)	B	60	119
6 (lead)	C	24.7	22

In each experiment, the spheres are mixed in a certain number of layers to make the packed bed, and the impurities of different diameters are used in the packed bed to measure the percent output of each case. Details are listed in the next section.

3.2 Steps of Experiments

The packed bed were made is consists of four sizes of glass spheres with diameters 10.6, 14.97, 20.89 and 25.84 mm .in each experiments a certain quantity of the four sizes of spheres and number percent were taken.

In each experiment, different numbers of layers (four, five, and six layers) were used. The following steps were taken in each experiment, and are listed as follows:-

1. The number percent of the four sizes of glass spheres were chosen.
2. A certain number of each type of the glass spheres are taken to make the first layer in the packed bed and this mixture is put inside the cylinder. This mixture has the same number percent that is chosen as in step 1.
3. The other layers are made and put it inside the cylinder to make the packed bed .the variable value in each experiments is the number percent of the mixture.
4. After the packed bed is completed inside the cylinder, the system is being ready to start, and entering a certain weight of the impurities and we start with group A from the top of the cylinder and by using the air of the compressor for 3 min. to reach the steady state, then the output of the impurities taken and weigh it by using the digital balance. And the procedure is repeated for mixtures B and C.
5. The above four steps are repeated for five and six layers of the packed beds with the same weight of impurities.

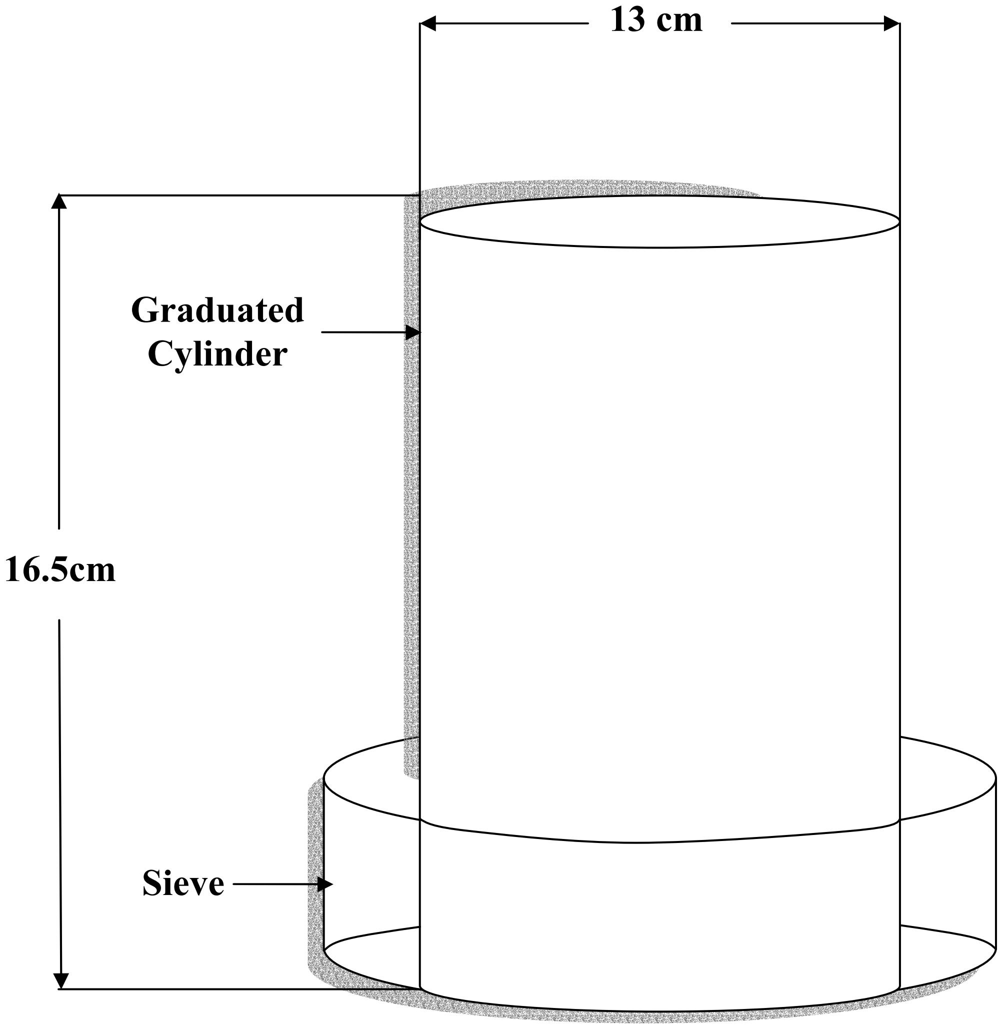


Fig.٣.1. Experimental work main system

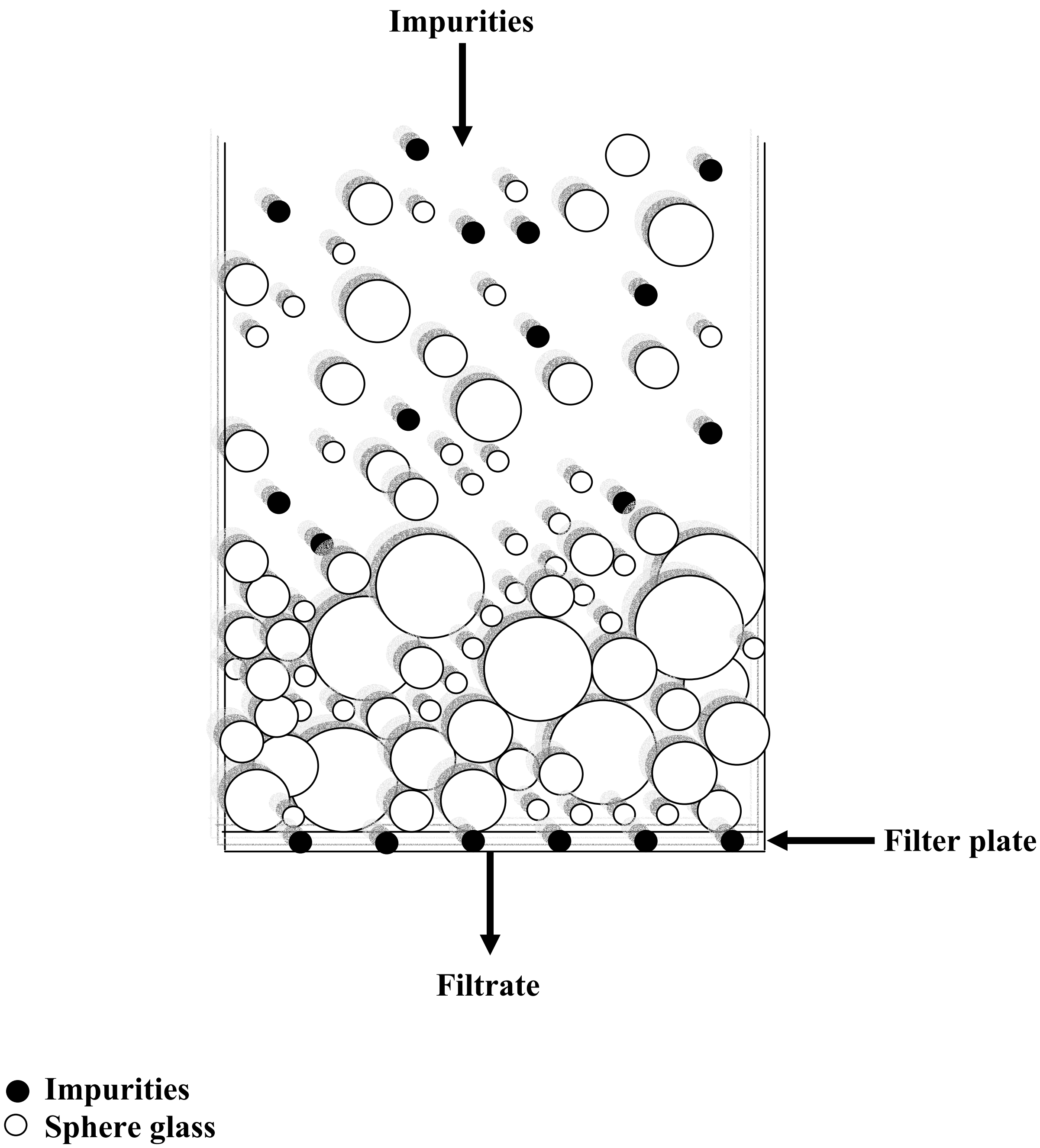


Fig. 3.2. Filter Aids model

Chapter Four

Results and Discussion

4.1 Introduction

In this section, the results of the calculation in the previous chapters will be applied for the four types of the packed bed.

Many experiments were done for the same number, composition, size, and diameters of the packed bed and impurities were used in chapter three.

Figures from 4.1 to 4.10 show the relationship between the probability and the diameter of the pores (d_c) for each distribution, and show the difference between the distributions of each case and this is the theoretical part.

The results of experimental and theoretical method will be related in a way that we can conclude relations between the mean pore diameter (d_{cm}) and percent output of impurities, also a relation between the number of layers and percent output and size of impurities and percent output.

4.2 Particle Separation

The experimental results for four, five, and six layers are given below, and ten experiments are done in each layer.

- **Experiment 1:**
    - Number of spheres of group 1=11
    - Number of spheres of group 2=11
    - Number of spheres of group 3=11
    - Number of spheres of group 4=11

N1=0.25, N2=0.25, N3=0.25, N4=0.25

Table 4.1 Results of Experiment 1

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	47	45.8	44.2
4.2	60	22	20	14.5
6	24.7	16.9	11.2	7.5
height of the bed (cm)		9	11	15

Percent output (wt. %)		
four layers	five layers	six layers
94	91.6	88.4
36.67	33.3	24.1
68.4	45.3	30.3

- **Experiment 2:**
    - Number of spheres of group 1=9
    - Number of spheres of group 2=13
    - Number of spheres of group 3=18
    - Number of spheres of group 4=5

N1=0.2, N2=0.3, N3=0.4, N4=0.1

Table 4.2 Results of experiment 2

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	46.6	44.8	40.6
4.2	60	36.2	18.3	18.1
6	24.7	12	9	8.5
height of the bed (cm)		10	10.5	13

Percent output (wt. %)		
four layers	five layers	six layers
93.2	89.6	81.2
60.3	30.5	30.1
48.5	36.4	34.4

- **Experiment 3:**
  - Number of spheres of group 1=23
  - Number of spheres of group 2=14
  - Number of spheres of group 3=10
  - Number of spheres of group 4=8

N1=0.42, N2=0.25, N3=0.18, N4=0.15

Table 4.3 Results of experiment 3

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	45.5	40.8	39.8
4.2	60	19.2	11.3	6
6	24.7	8.6	5.6	3.8
height of the bed (cm)		8	11	15

Percent output (wt. %)		
four layers	five layers	six layers
91	81.6	79.6
32	18.8	10
34.8	22.6	15.4

- **Experiment 4:**
  - Number of spheres of group 1=30
  - Number of spheres of group 2=20
  - Number of spheres of group 3=6
  - Number of spheres of group 4=4

N1=0.5, N2=0.34, N3=0.1, N4=0.06

Table 4.4 Results of experiment 4

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	44.8	35	31
4.2	60	29.1	16.5	9.8
6	24.7	6	4.5	1.9
height of the bed (cm)		6	7	10

Percent output (wt. %)		
four layers	five layers	six layers
89.6	70	62
48.5	27.5	16.3
24.3	18.2	7.7

- **Experiment 5:**
    - Number of spheres of group 1=20
    - Number of spheres of group 2=15
    - Number of spheres of group 3=7
    - Number of spheres of group 4=10

N1=0.38, N2=0.29, N3=0.13, N4=0.2

Table 4.5 Results of experiment 5

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	45.1	43.4	38.9
4.2	60	22.5	15.5	13.3
6	24.7	10	8.8	4.5
height of the bed (cm)		9	12	13

Percent output (wt. %)		
four layers	five layers	six layers
90.2	86.8	77.8
37.5	25.9	22.1
40.5	35.6	18.2

- **Experiment 6:**
  - Number of spheres of group 1=12
  - Number of spheres of group 2=8
  - Number of spheres of group 3=12
  - Number of spheres of group 4=8

N1=0.3, N2=0.2, N3=0.3, N4=0.2

Table 4.6 Results of experiment 6

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	46.7	45	45.9
4.2	60	31	25.1	18.8
6	24.7	11.6	9.5	6
height of the bed (cm)		8.5	11	13

Percent output (wt. %)		
four layers	five layers	six layers
93.4	90	91.8
51.6	41.8	31.3
47	38.5	24.3

- **Experiment 7:**
  - Number of spheres of group 1=10
  - Number of spheres of group 2=14
  - Number of spheres of group 3=6
  - Number of spheres of group 4=10

N1=0.25, N2=0.35, N3=0.15, N4=0.25

Table 4.7 Results of experiment 7

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	46.3	45.5	44.2
4.2	60	33	26.4	18.9
6	24.7	14.5	8.5	5
height of the bed (cm)		9	10	12.5

Percent output (wt. %)		
four layers	five layers	six layers
92.6	91	88.4
55	44	31.5
48.7	34.4	20.2

- **Experiment 8:**
    - Number of spheres of group 1=40
    - Number of spheres of group 2=12
    - Number of spheres of group 3=12
    - Number of spheres of group 4=2

N1=0.6, N2=0.18, N3=0.18, N4=0.03

Table 4.8 Results of experiment 8

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	42.3	37.4	27
4.2	60	40	25	6.6
6	24.7	3	1.6	0.6
height of the bed (cm)		6	8	9

Percent output (wt. %)		
four layers	five layers	six layers
84.6	74.8	54
66.6	41.6	11
12.1	6.5	2.4

- **Experiment 9:**
  - Number of spheres of group 1=7
  - Number of spheres of group 2=2
  - Number of spheres of group 3=11
  - Number of spheres of group 4=11

N1=0.23, N2=0.07, N3=0.35, N4=0.35

Table 4.9 Results of experiment 9

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	49.1	48.1	47.8
4.2	60	36.5	23.3	17.9
6	24.7	12	9.5	6
height of the bed (cm)		8	9	12

Percent output (wt. %)		
four layers	five layers	six layers
98.2	96.2	95.6
60.8	38.8	29.8
48.5	38.5	24.3

- **Experiment 10:**
    - Number of spheres of group 1=60
    - Number of spheres of group 2=10
    - Number of spheres of group 3=11
    - Number of spheres of group 4=2

N1=0.8, N2=0.04, N3=0.13, N4=0.03

Table 4.10Results of experiment 10

Size of impurities (mm)	Weight of spheres (input)(gm)	Weight of spheres output (gm)		
		four layers	five layers	six layers
1.2-3.3	50	24.8	19.7	16.1
4.2	60	22	14.2	3.7
6	24.7	2	1.2	0
height of the bed (cm)		7	7.5	8.5

Percent output (wt. %)		
four layers	five layers	six layers
49.6	39.4	32.3
36.6	23.6	6.2
8	4.8	0

4.3 Prediction of Pore Size

The pore size diameter (d_c) which is represented in X-axis calculated from the computer program and the results listed in appendix C. and the probability which is represented in Y-axis calculated from the computer program listed in appendix B.

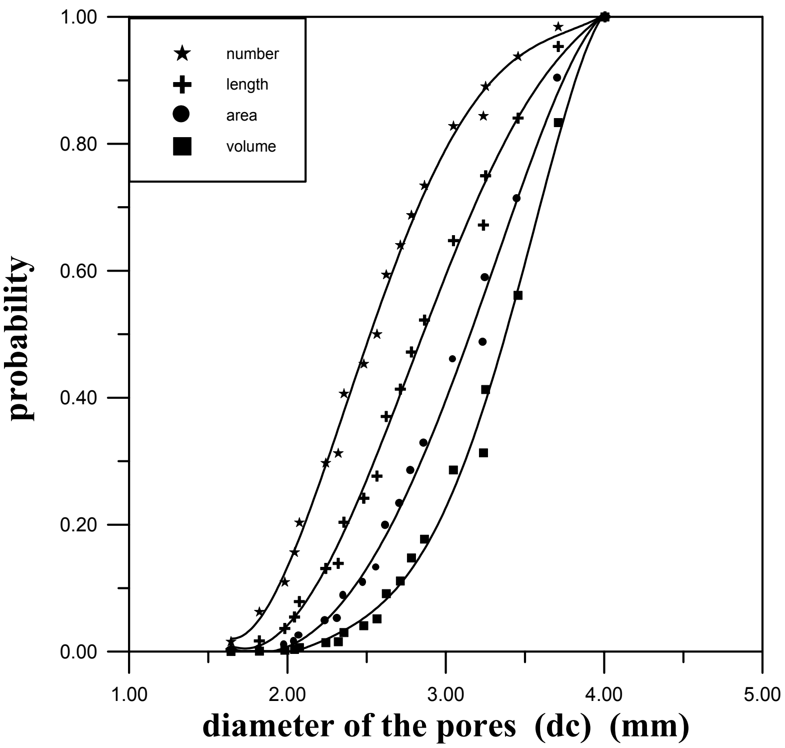


Fig. 4.1. Pore size distribution due to number, length, area, volume for: N1=0.25, N2=0.25, N3=0.25, N4=0.25

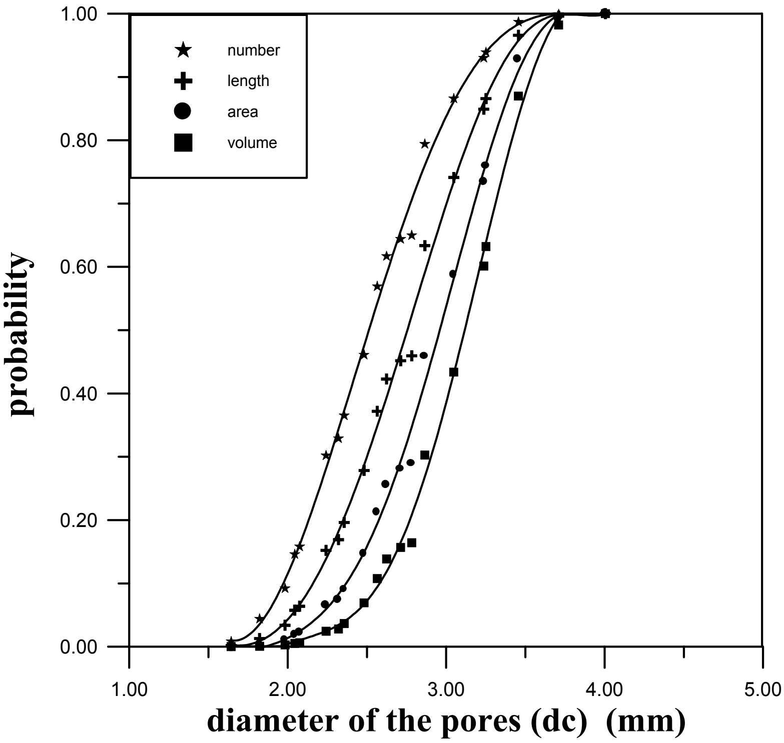


Fig. 4.2. Pore size distribution due to number, length, area, volume for:

N1=0.20, N2=0.30, N3=0.40, N4=0.10

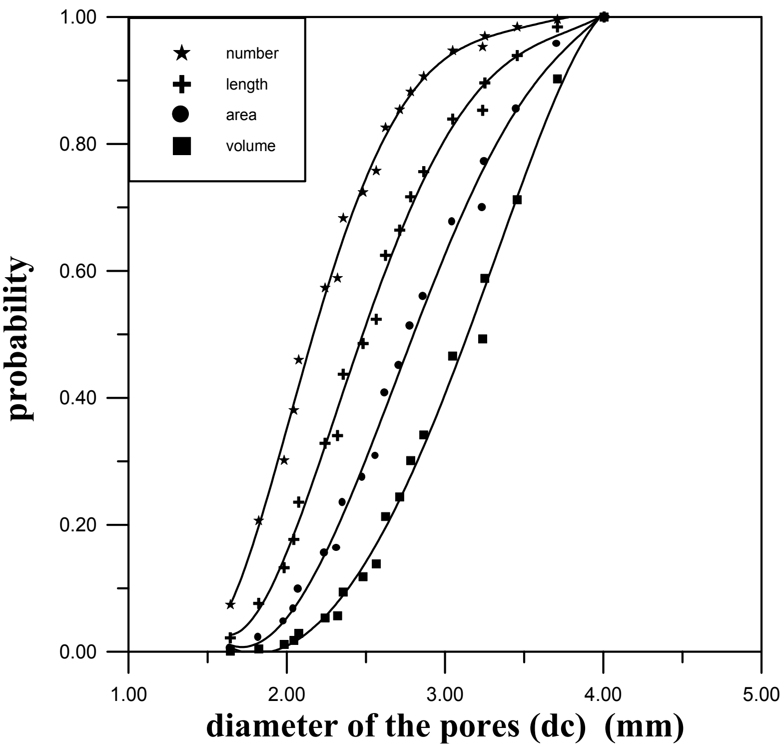


Fig. 4.3.Pore size distribution due to number, length, area, volume for:

N1=0.42, N2=0.25, N3=0.18, N4=0.15

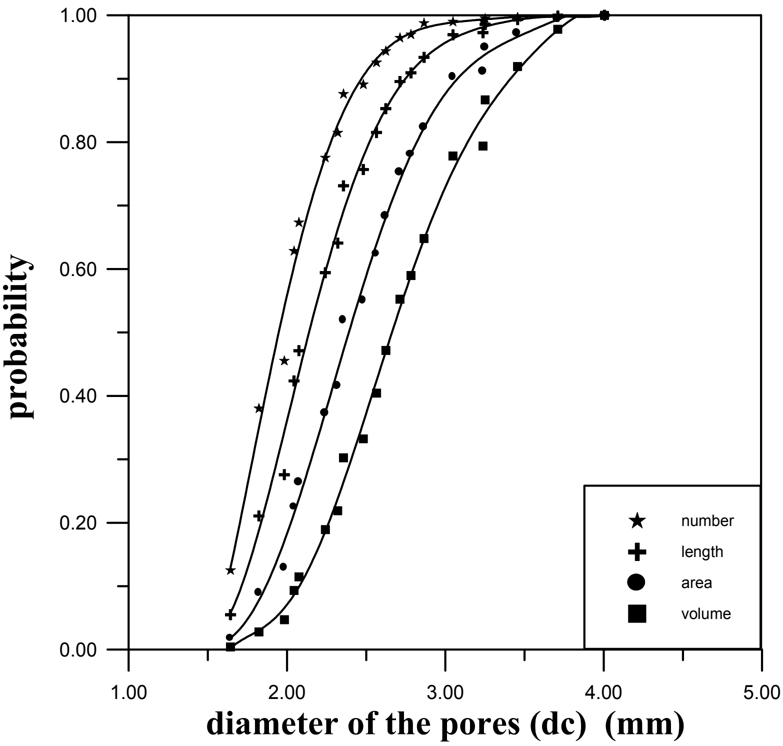


Fig. 4.4. Pore size distribution due to number, length, area, volume for: N1=0.50, N2=0.34, N3=0.10, N4=0.06

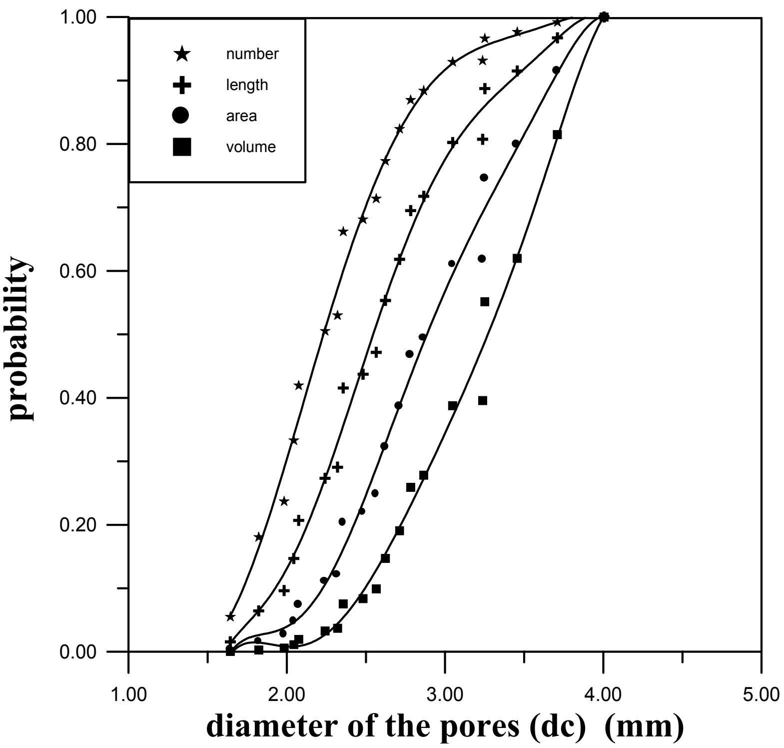


Fig. 4.5. Pore size distribution due to number, length, area, volume for: N1=0.38, N2=0.29, N3=0.13, N4=0.20

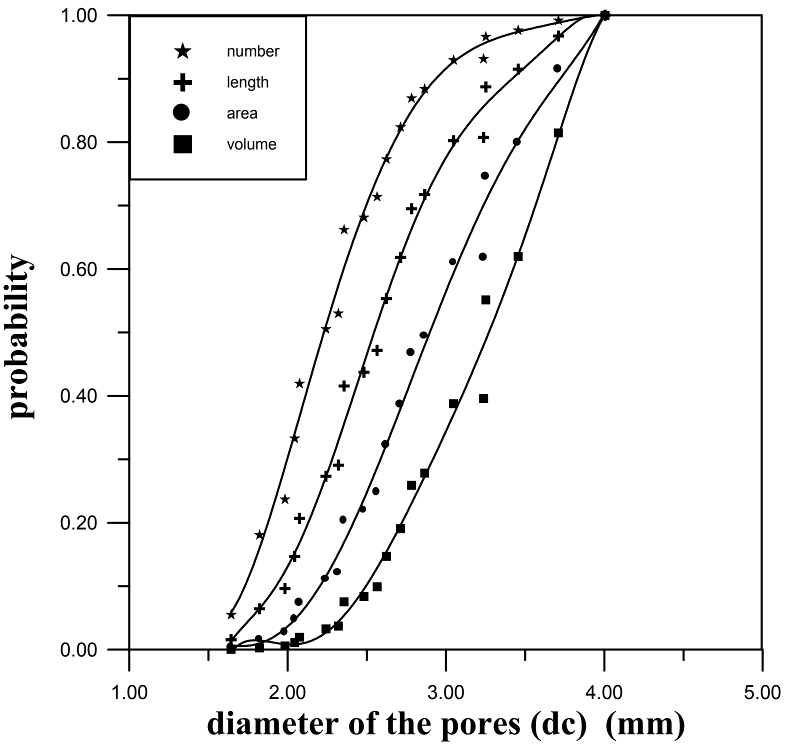


Fig. 4.6. Pore size distribution due to number, length, area, volume for: N1=0.30, N2=0.20, N3=0.30, N4=0.20

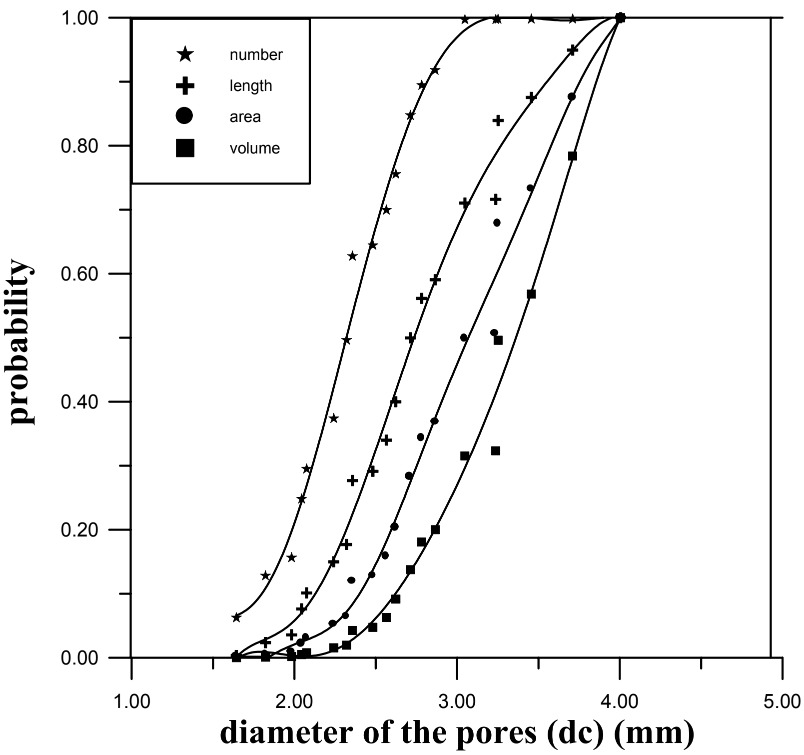


Fig. 4.7. pore size distribution due to number, length, area, volume for: N1=0.25, N2=0.35, N3=0.15, N4=0.25

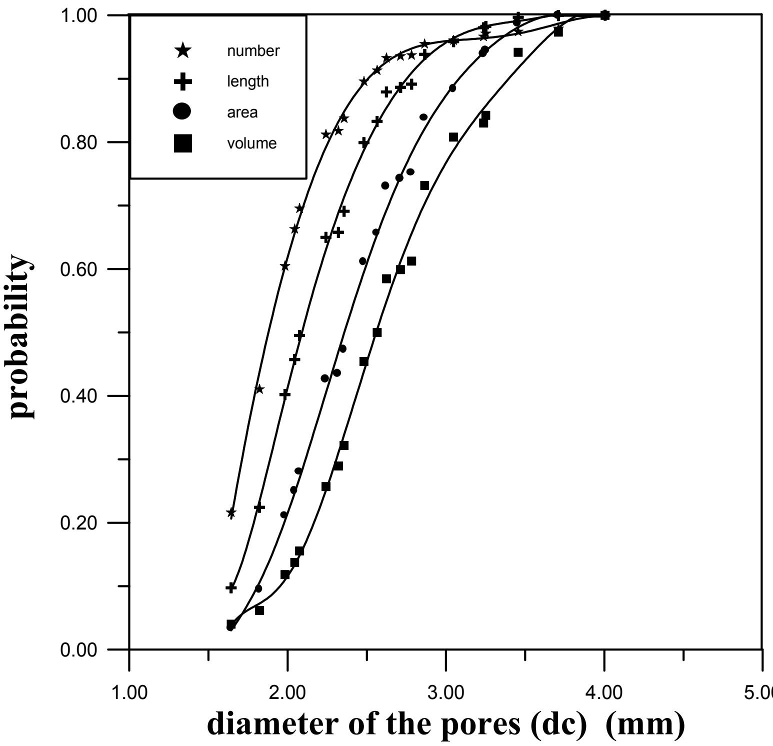


Fig. 4.8. Pore size distribution due to number, length, area, volume for:

N1=0.60, N2=0.18, N3=0.18, N4=0.03

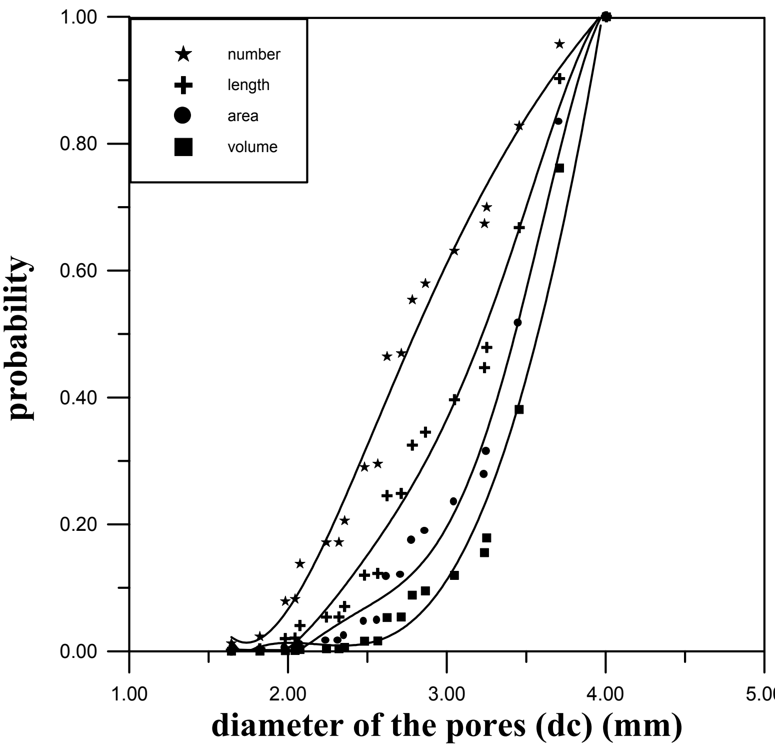


Fig. 4.9. Pore size distribution due to number, length, area, volume for:

N1=0.23, N2=0.07, N3=0.35, N4=0.35

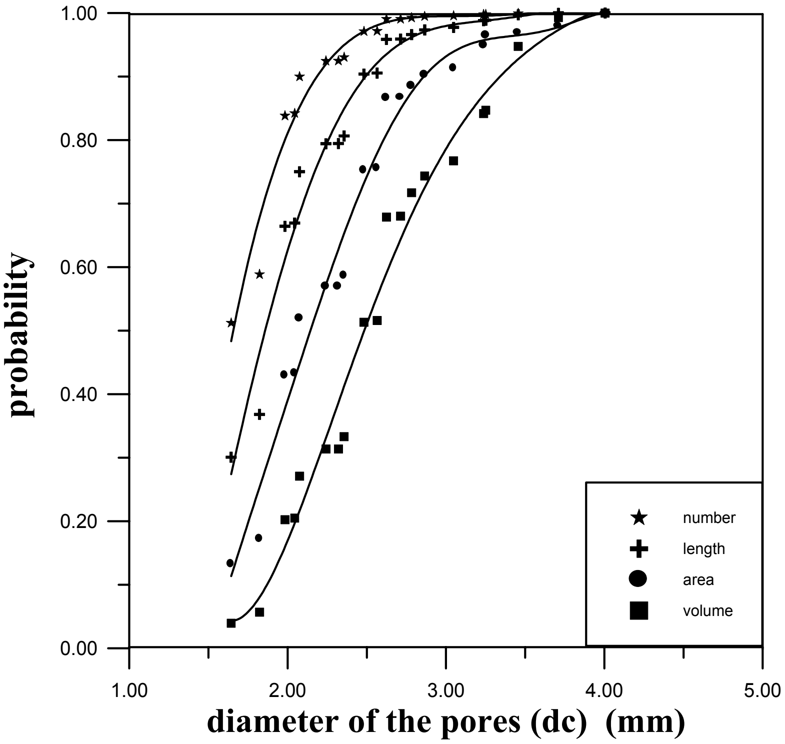


Fig. 4.10. Pore size distribution due to number, length, area, volume for: N1=0.80, N2=0.04, N3=0.13, N4=0.03

4.4. Relationships between Mean Pore Diameter and Percent output of Impurities

The constant parameters in this work are the diameters of the packed bed .as shown in the first chapters of this research, these diameters are 10.6, 14.97, 20.89, and 25.84 mm respectively.

The number percent distribution is the start point, because the composition of the packed bed in the experimental work depends on the number percent, then the conversion to the other distribution, which is due to length, area, and volume will be made with their relations and percent output of impurities.

The mean pore diameter due to number, length, area, and volume will be related with three types of impurities that passes through the packed bed layers and these types of impurities are:

1. spheres of 1.2-3.3 mm

2. spheres of 4.2 mm

3. spheres of 6 mm

The mean pore size and the weight percent of impurities will be related in this section for each packed bed made four sizes of spheres. In spite of the variety of the composition of different packing, the mean pore size is the same calculated.

The figures from (4.11) to (4.13) show the relationship between the mean pore diameter (dc_m) due to number with percent output of impurities for four, five, and six layers.

The reason of the distribution points from fig.4.11 to 4.13 was because the mean pore diameter was selected randomly not under specific rules.

The figures from (4.11) to (4.13) show the proportionality between the mean pore diameter and the percent output for number percent distribution for four, five, and six layers and they are proportional to each other, and these figures show intersection points in 4.2mm and 6mm for four and five layers because the percent output was sometimes the same.

Figures from 4.14-4.22 show the distribution points because the mean pore diameter was taken for different assumed distribution not under specific rules.

From the above relations it is clear that the curve of the small mixture has higher values of percent output (e.g. the curve of 1.2-3.3 mm mixture) and the curve of the large diameter of impurities has smaller values of percent output for the three layers.

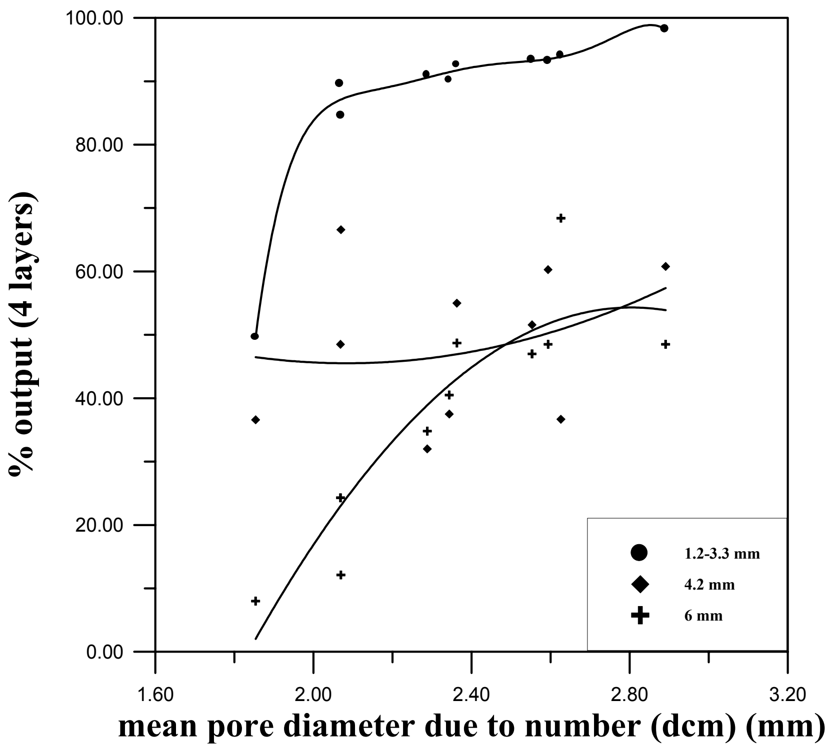


Fig. 4.11 Mean pore diameter due to number vs. percent output (four layers)

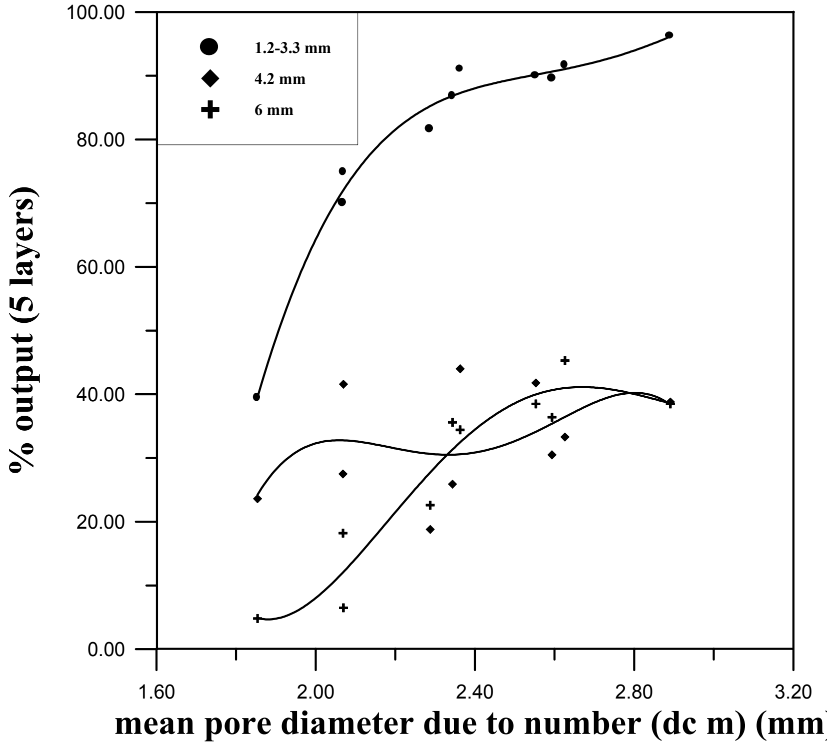


Fig. 4.12 Mean pore diameter due to number vs. percent output (five layers)

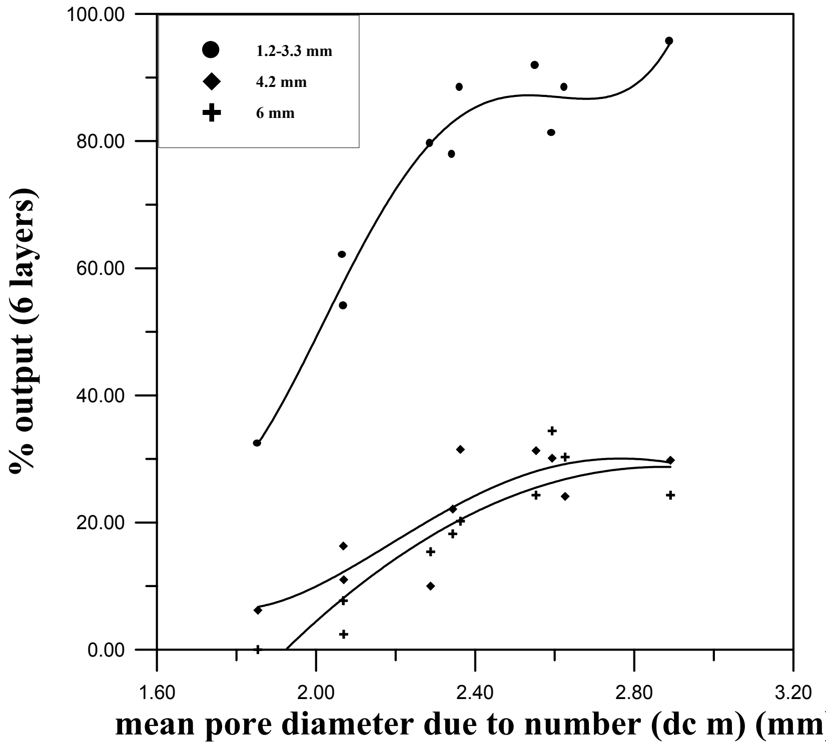


Fig. 4.13 Mean pore diameter due to number vs. percent output (six layers)

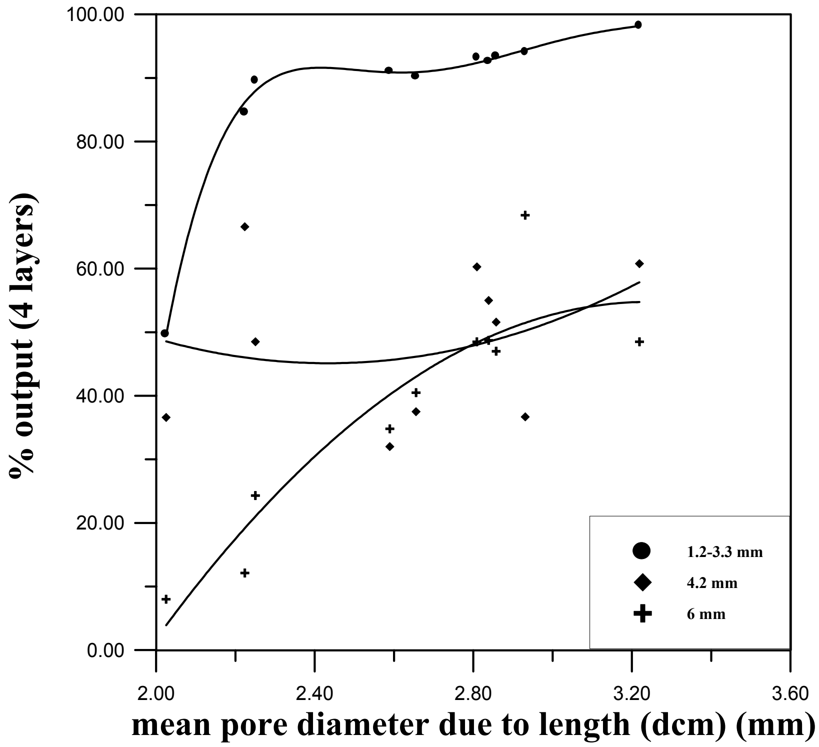


Fig. 4.14 Mean pore diameter due to length vs. percent output (four layers)

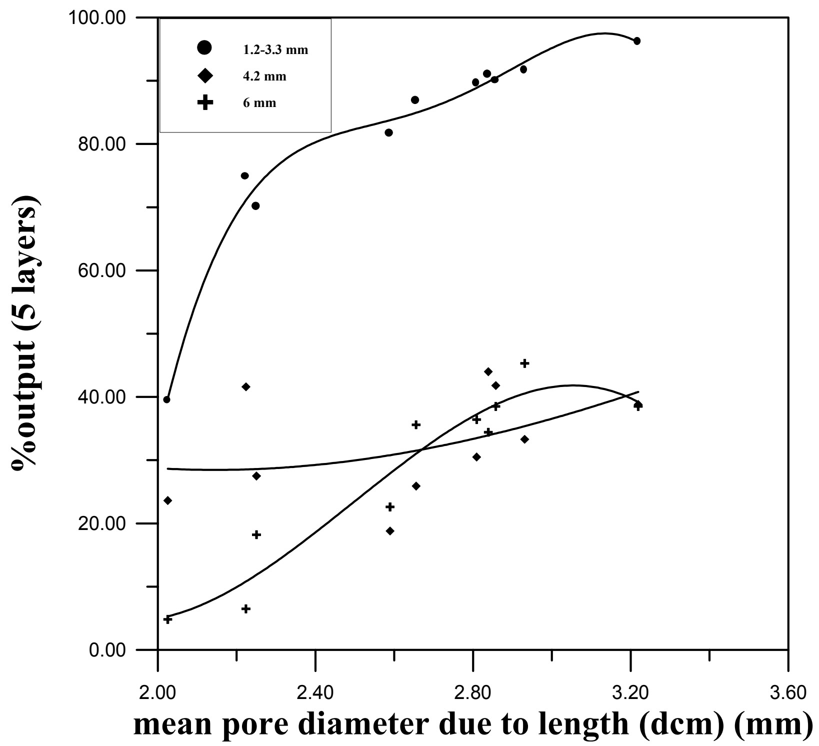


Fig. 4.15 Mean pore diameter due to length vs. percent output (five layers)

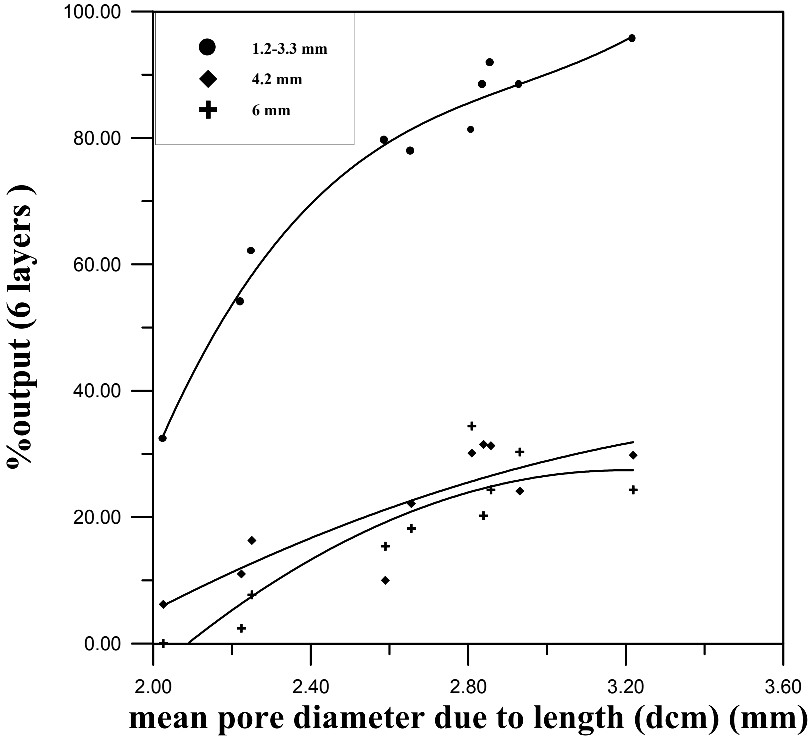


Fig. 4.16 Mean pore diameter due to length vs. percent output (six layers)

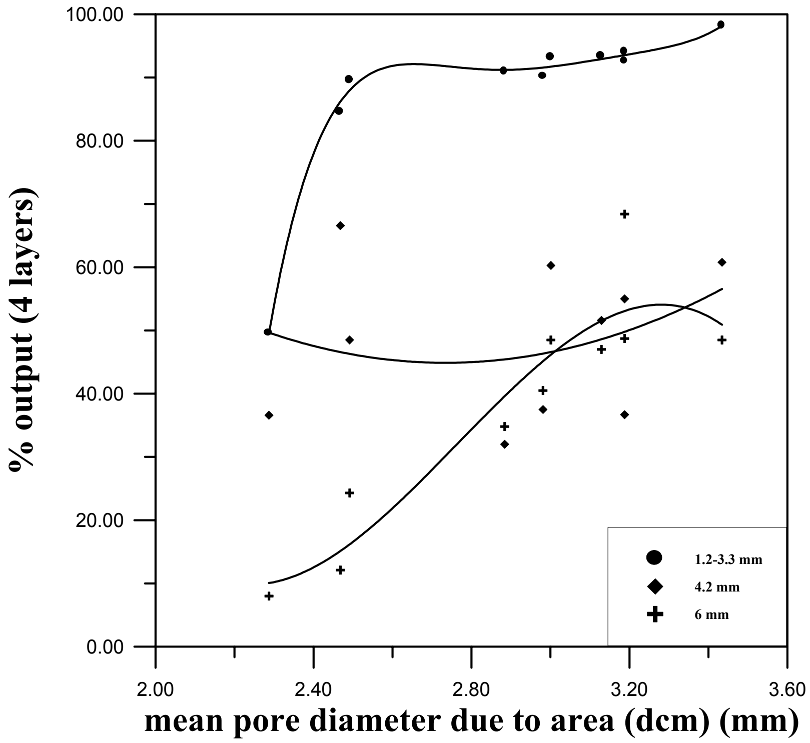


Fig. 4.17 Mean pore diameter due to area vs. percent output (four layers)

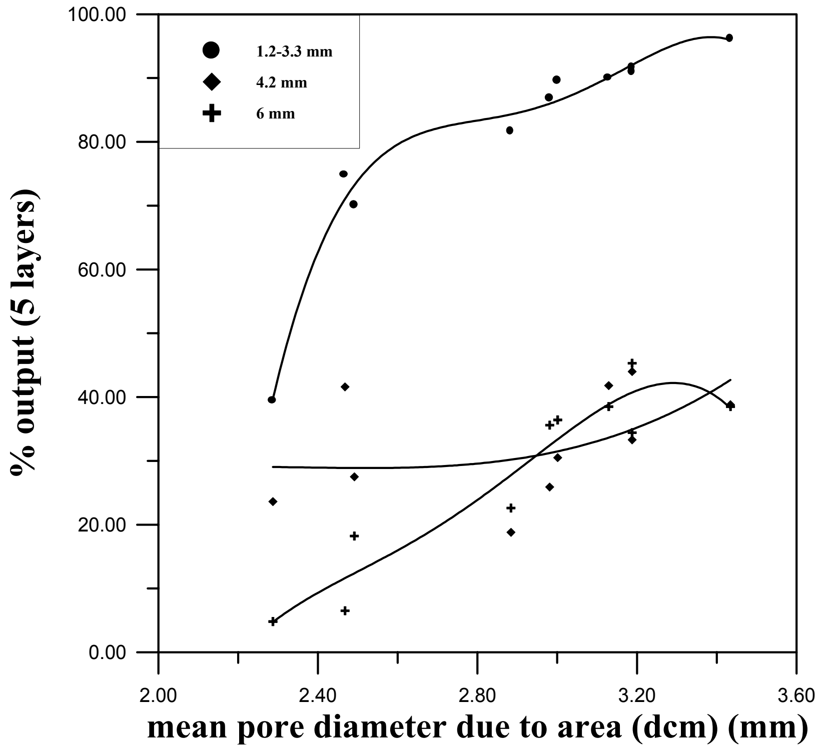


Fig. 4.18 Mean pore diameter due to area vs. percent output (five layers)

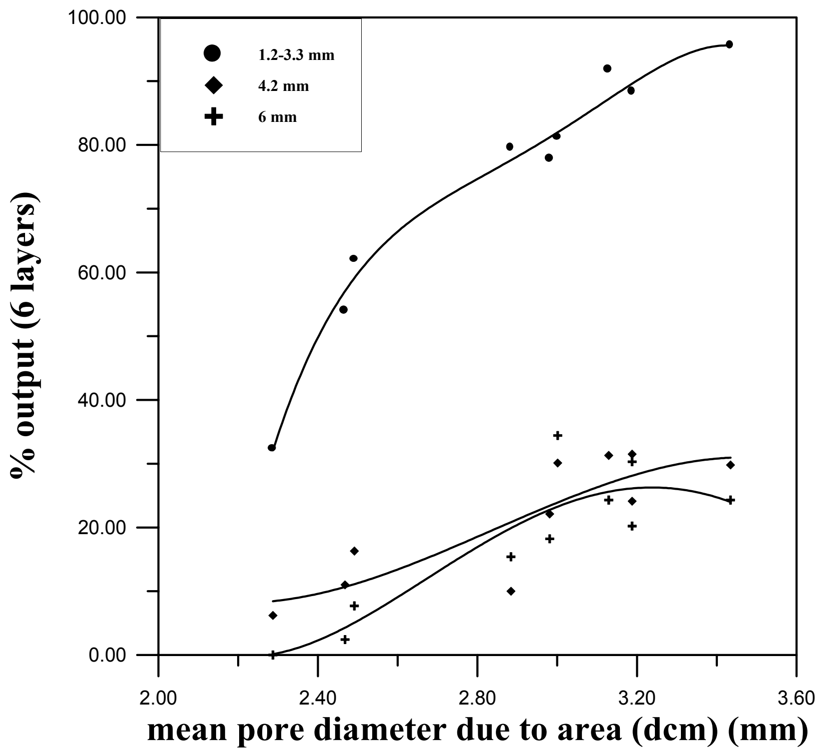


Fig. 4.19 Mean pore diameter due to area vs. percent output (six layers)

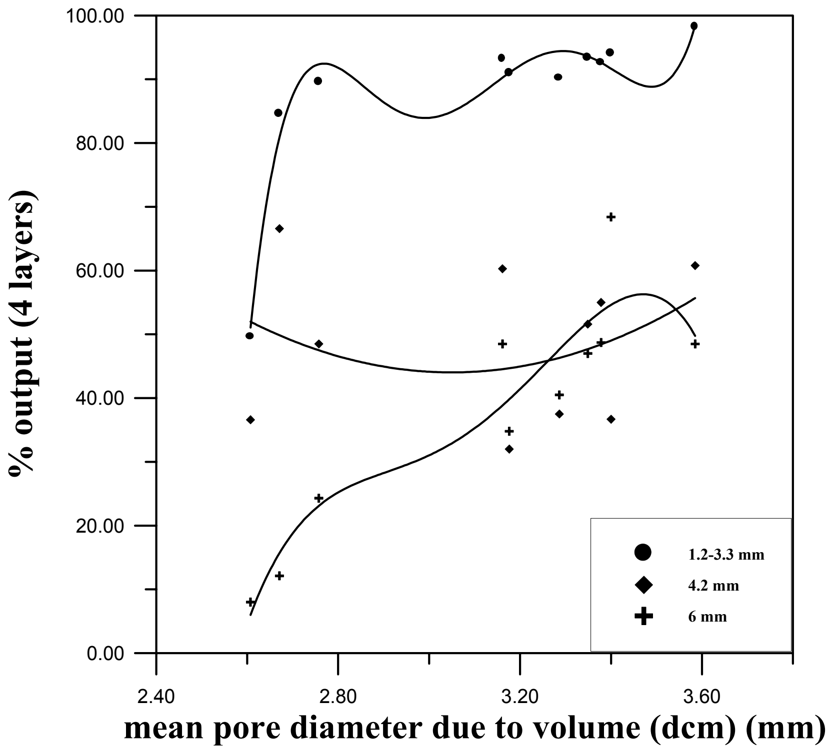


Fig. 4.20 Mean pore diameter due to volume vs. percent output (four layers)

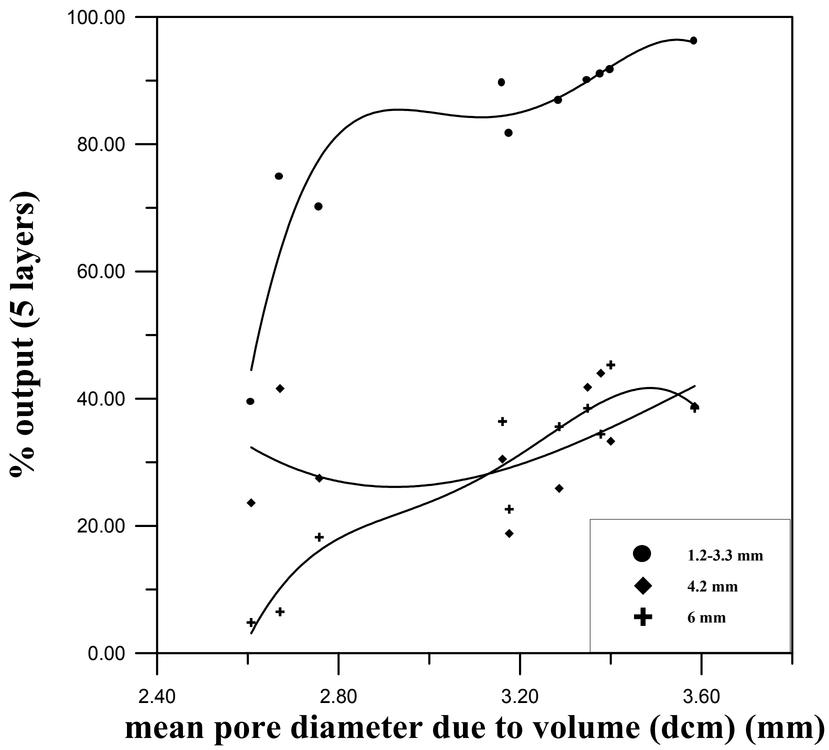


Fig. 4.21 Mean pore diameter due to volume vs. percent output (five layers)

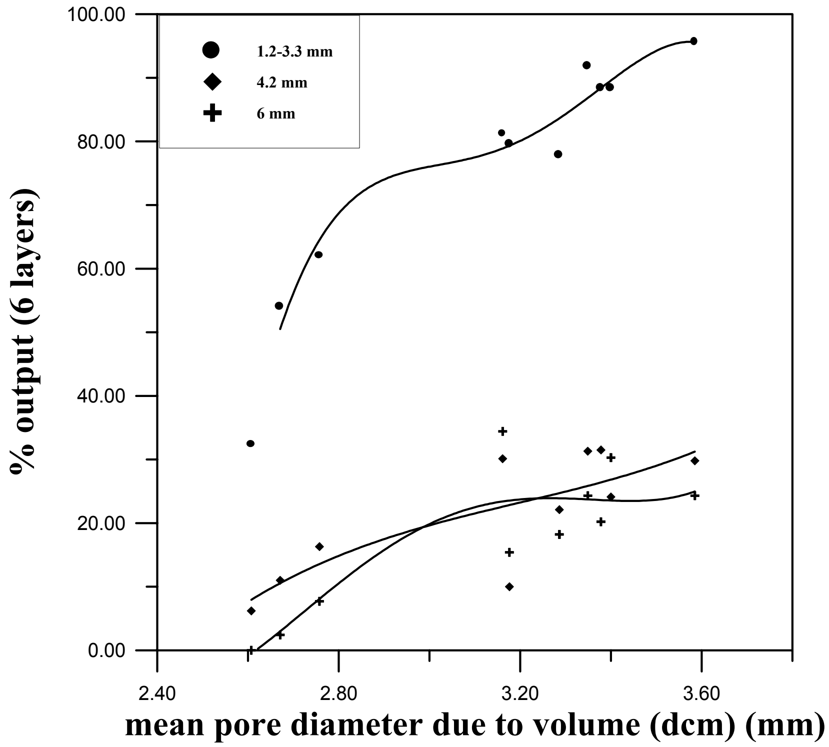


Fig. 4.22 Mean pore diameter due to volume vs. percent output (six layers)

4.5 Relation between Size of Impurities and Percent Output of Impurities

Figures from (4.23) to (4.32) represent this relation and three sizes of impurities are taken and percent outputs of impurities are taken from the experimental work results.

It is clear that the curves in the figures below for four, five, and six layers shows that the percent output of impurities decreasing with increasing the size of impurities and this is clear in the first two points of each curve . But in size 6 mm points for the three curves in figures 5.23, 5.24, 5.25, and 5.27 the percent output of impurities will increase with decreasing the size of impurities and this make sure that the exist of bigger pores than the theoretical maximum pores, but the effect of these pores is reduce and disappear when increasing the number of layers, and the number of available pores for passing the first particle, which has volume of 6 mm and that will be more than the available particles for the smaller particles and that leading to increase the probability of configuration the bridge between the little particles and that will prohibit the little particles from passing through a good pores for passing particles as a speed not a pile.

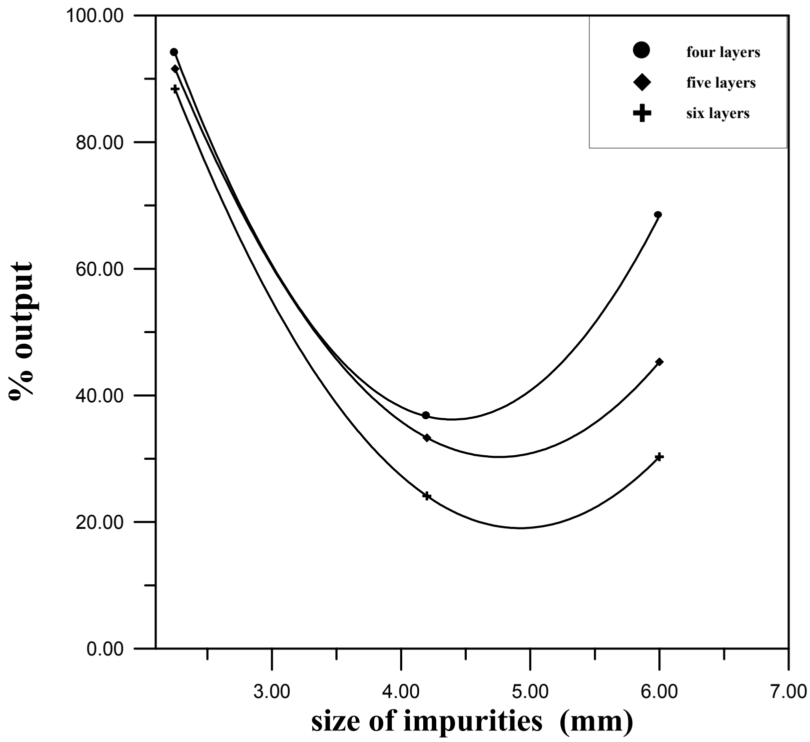


Fig. 4.23 size of impurities vs. percent output for: N1=0.25, N2=0.25, N3=0.25, N4=0.25

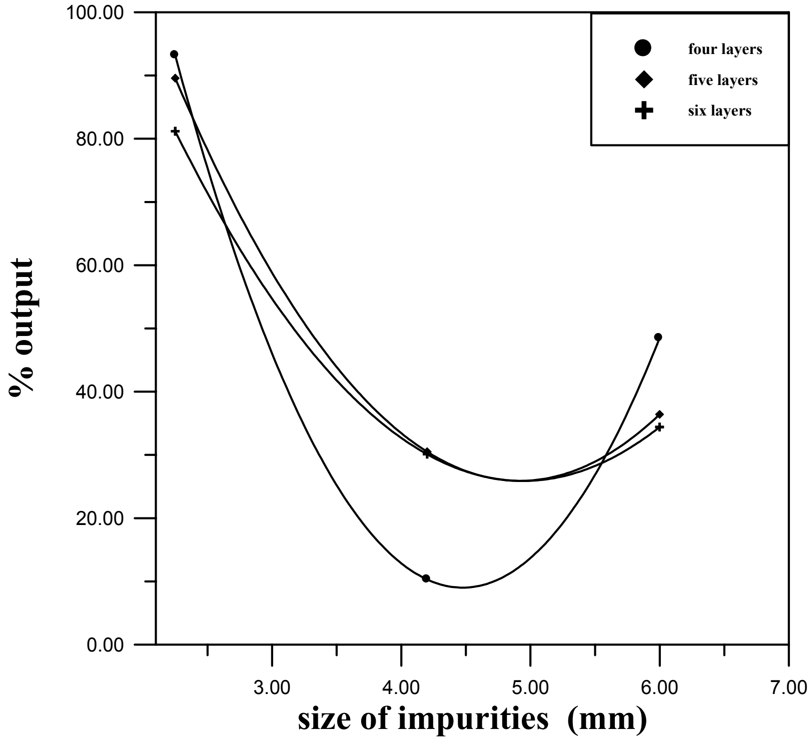


Fig. 4.24 size of impurities vs. percent output for: N1=0.2, N2=0.3, N3=0.4, N4=0.1

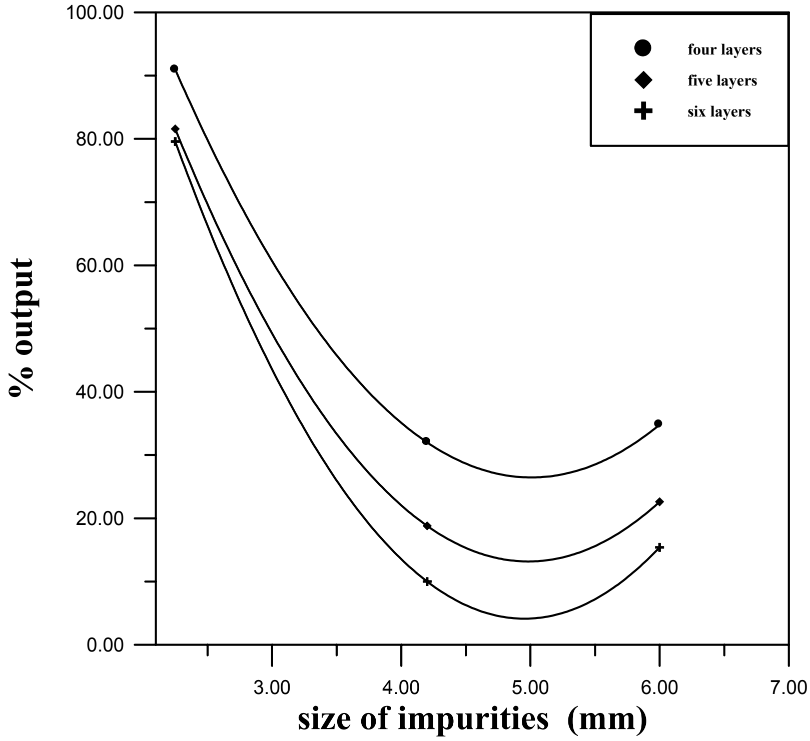
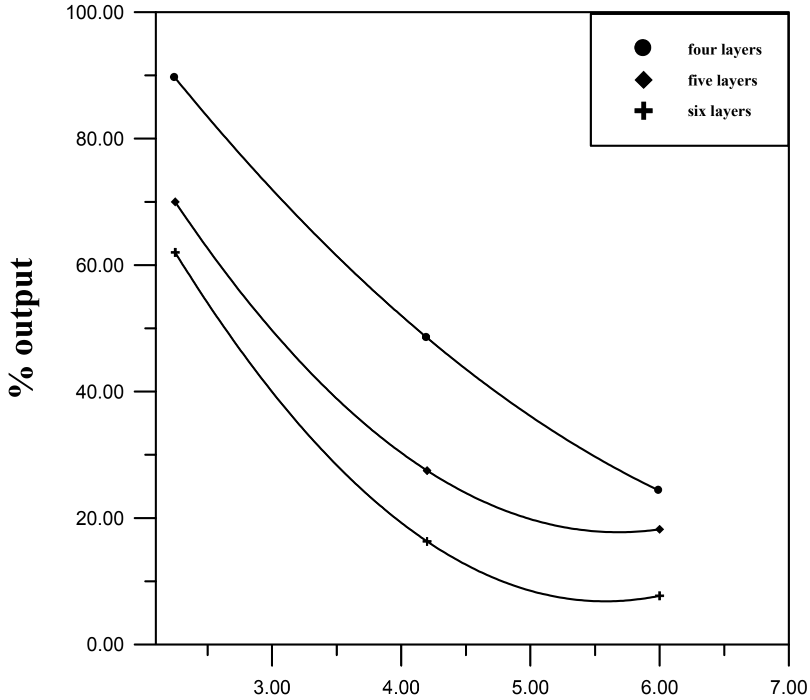
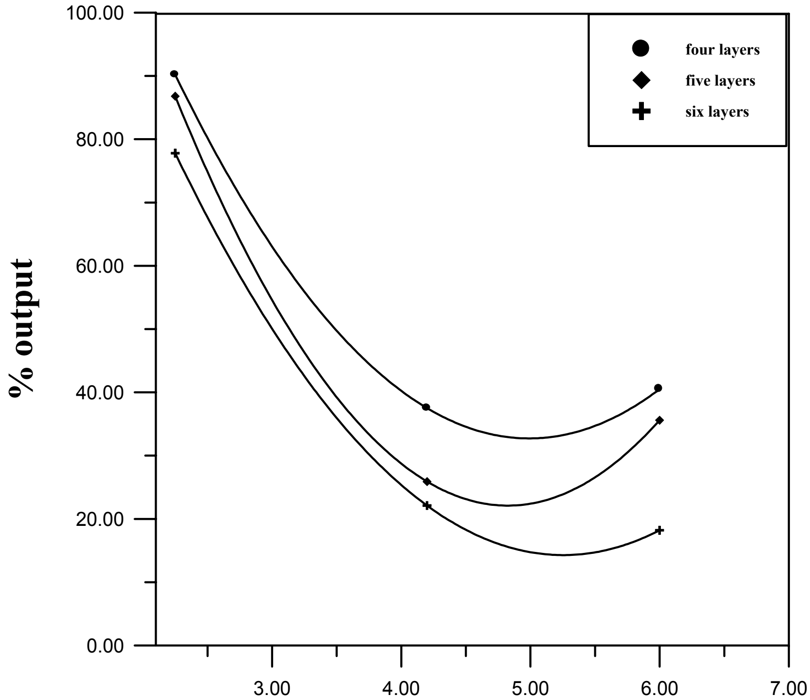


Fig. 4.25 size of impurities vs. percent output for: N1=0.42, N2=0.25, N3=0.18, N4=0.15



size of impurities (mm)

Fig. 4.26 size of impurities vs. percent output for: N1=0.5, N2=0.34, N3=0.1, N4=0.06



size of impurities (mm)

Fig. 4.27 size of impurities vs. percent output for: N1=0.38, N2=0.29, N3=0.13, N4=0.2

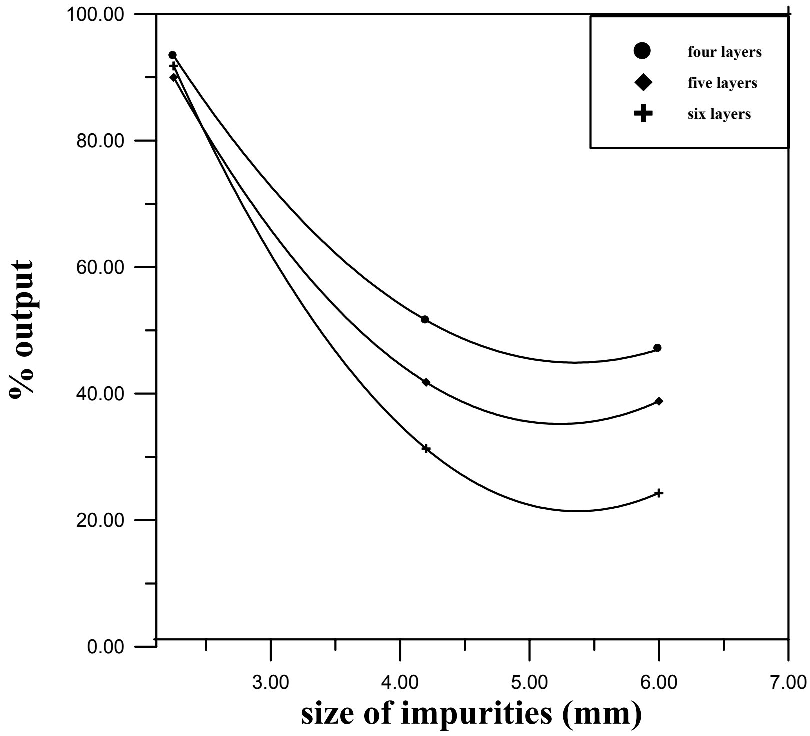


Fig. 4.28 size of impurities vs. percent output for: N1=0.3, N2=0.2, N3=0.3, N4=0.2

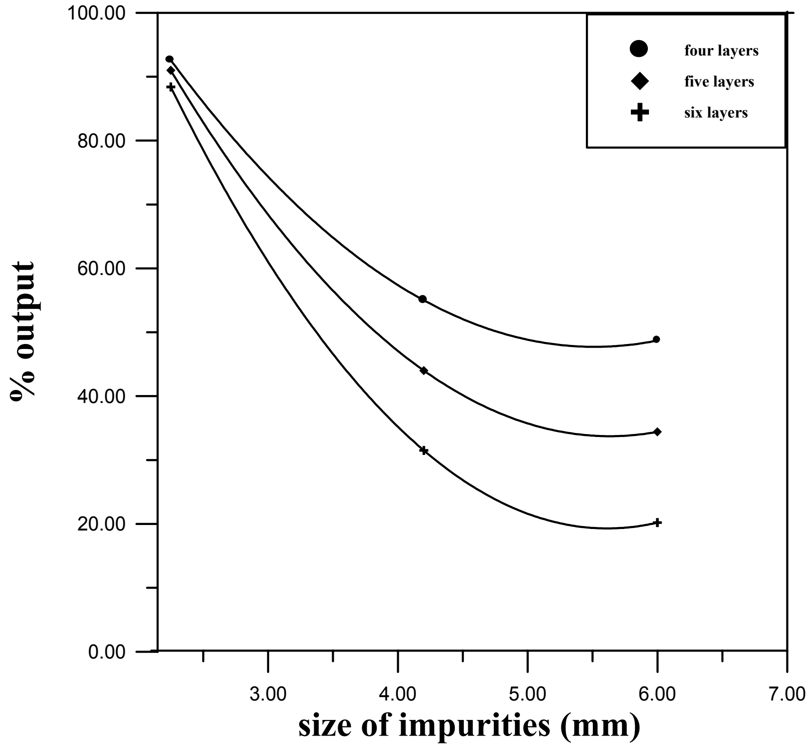


Fig. 4.29 size of impurities vs. percent output for: N1=0.25, N2=0.35, N3=0.15, N4=0.25

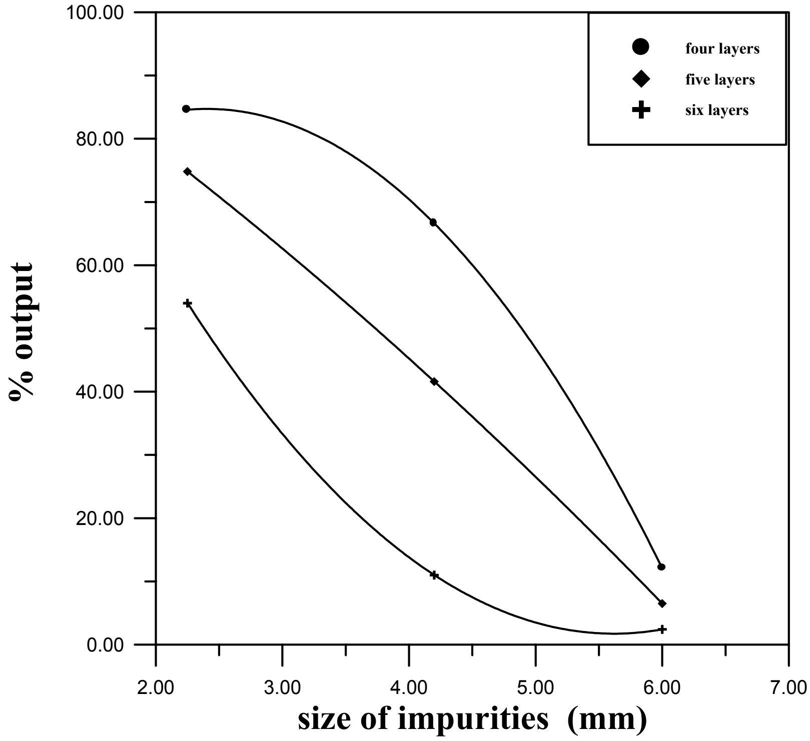


Fig. 4.30 size of impurities vs. percent output for:
N1=0.6, N2=0.18, N3=0.18, N4=0.03

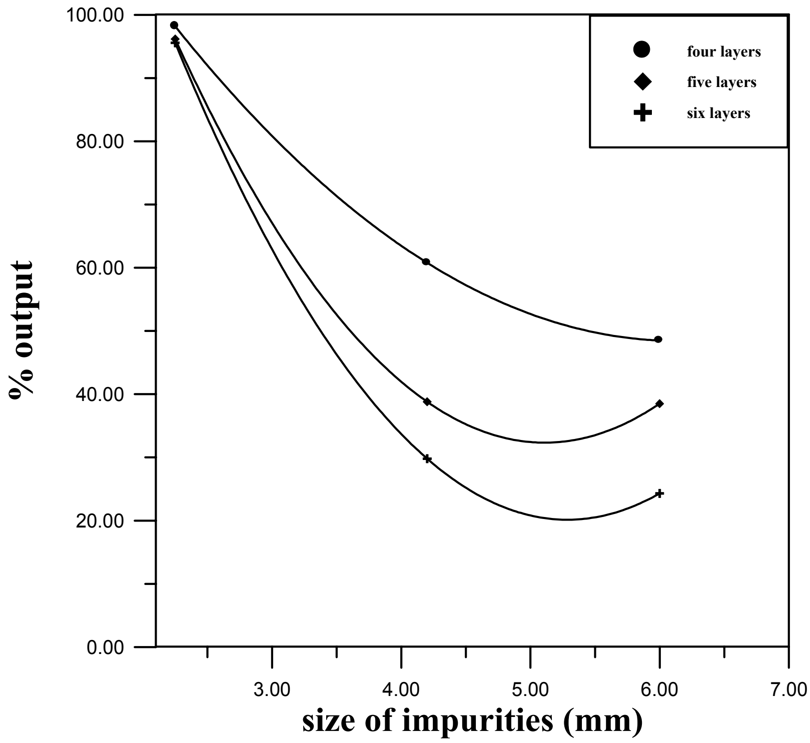


Fig. 4.31 size of impurities vs. percent output for:
N1=0.23, N2=0.07, N3=0.35, N4=0.35

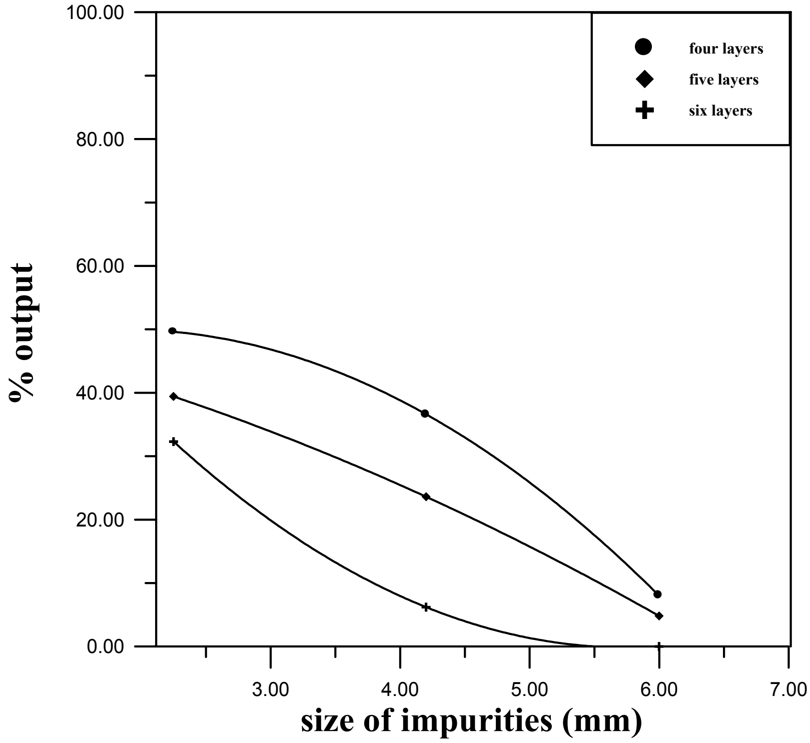


Fig. 4.32 size of impurities vs. percent output for: N1=0.8, N2=0.04, N3=0.13, N4=0.03

4.6 Relation between Number of Layers and Percent Output of Impurities

In this relation, the variety of the curves can be seen widely; figures from (4.33) to (4.42) represent this relation and each curve represents the size of impurities for four, five, and six layers. The proportionality between the size of impurities and percent output is inversely.

Figure 4.33 shows that the smaller size of impurities (1.2-3.3 mm) has the higher value of percent output because the diameter of the pores for the packed bed larger than the diameter of the impurities so, the weight of this type of impurities that leaves the packed bed is very closely to the input weight.

The third curve of impurities (6 mm) has smaller value of percent output. The variety in the shape of the curves is coming from the variety of the composition of the spheres in the packed bed as shown in figures below.

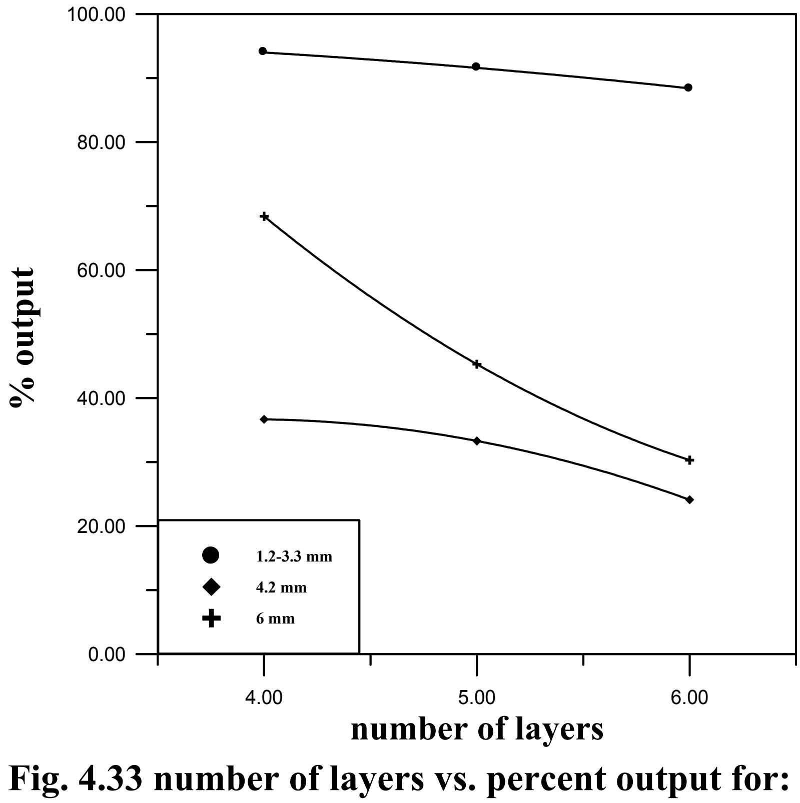


Fig. 4.33 number of layers vs. percent output for: N1=0.25, N2=0.25, N3=0.25, N4=0.25

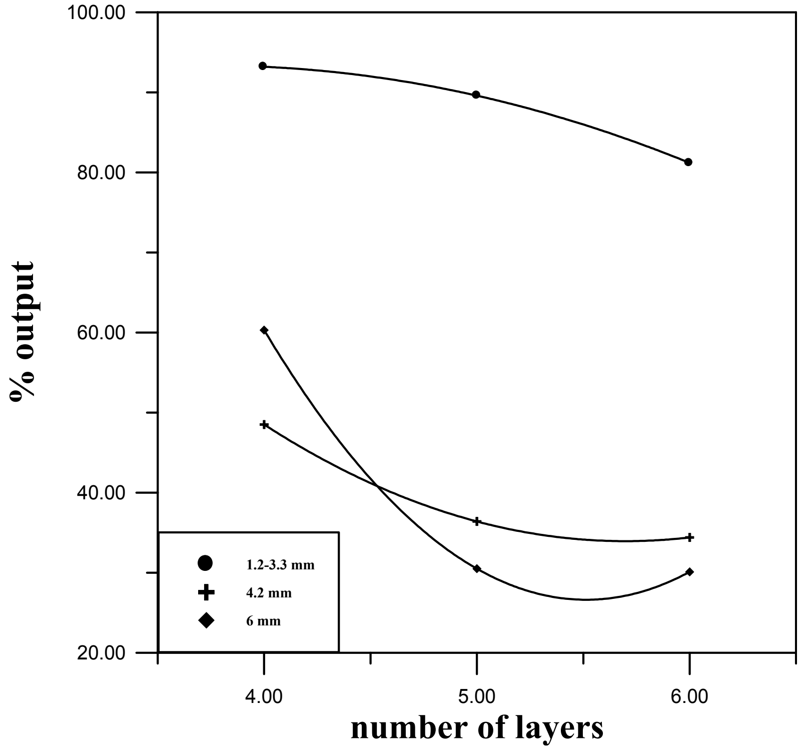


Fig. 4.34 number of layers vs. percent output for: N1=0.2, N2=0.3, N3=0.4, N4=0.1

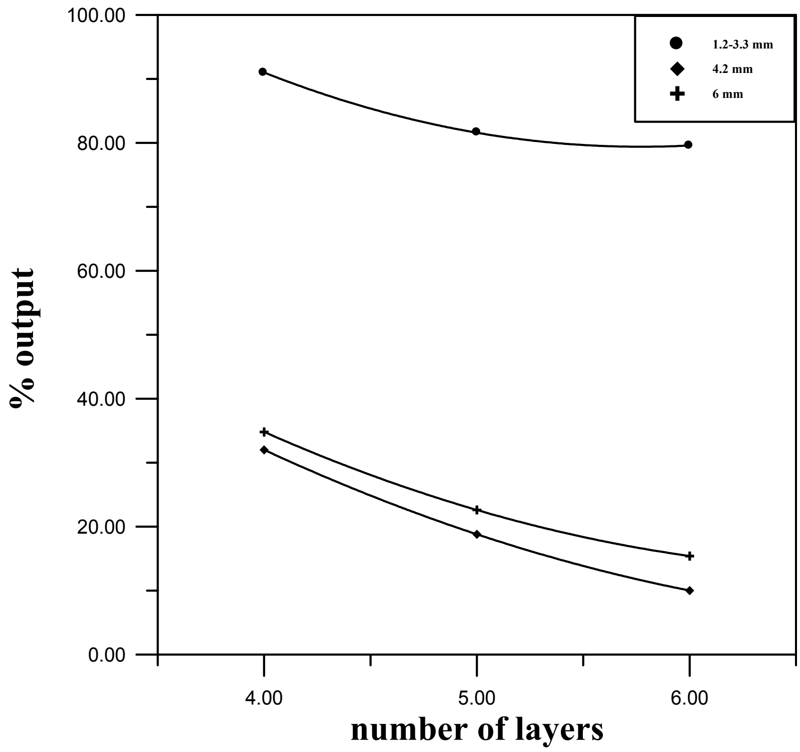


Fig. 4.35 number of layers vs. percent output for: N1=0.42, N2=0.25, N3=0.18, N4=0.15

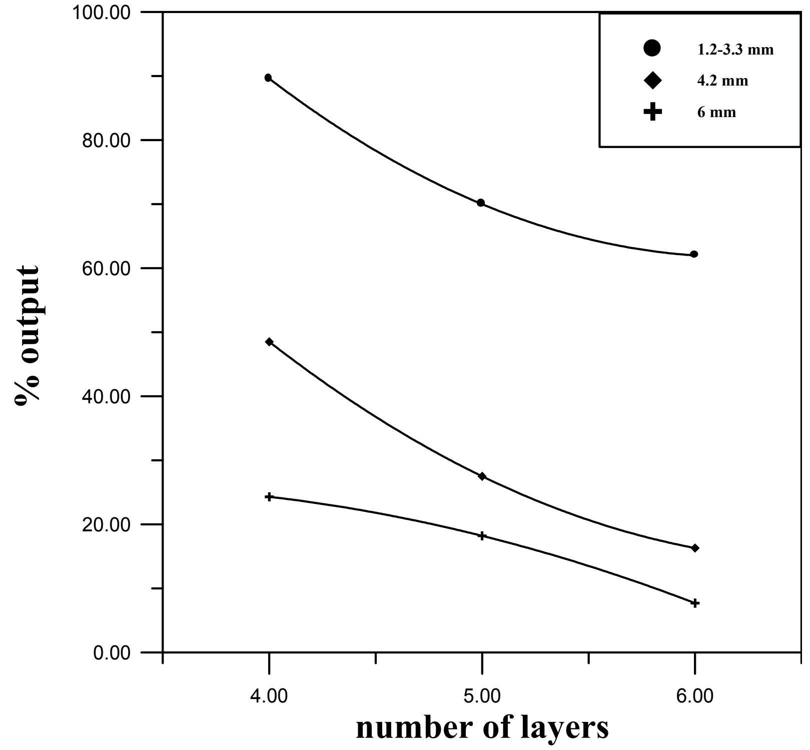


Fig. 4.36 number of layers vs. percent output for: N1=0.5, N2=0.34, N3=0.1, N4=0.06

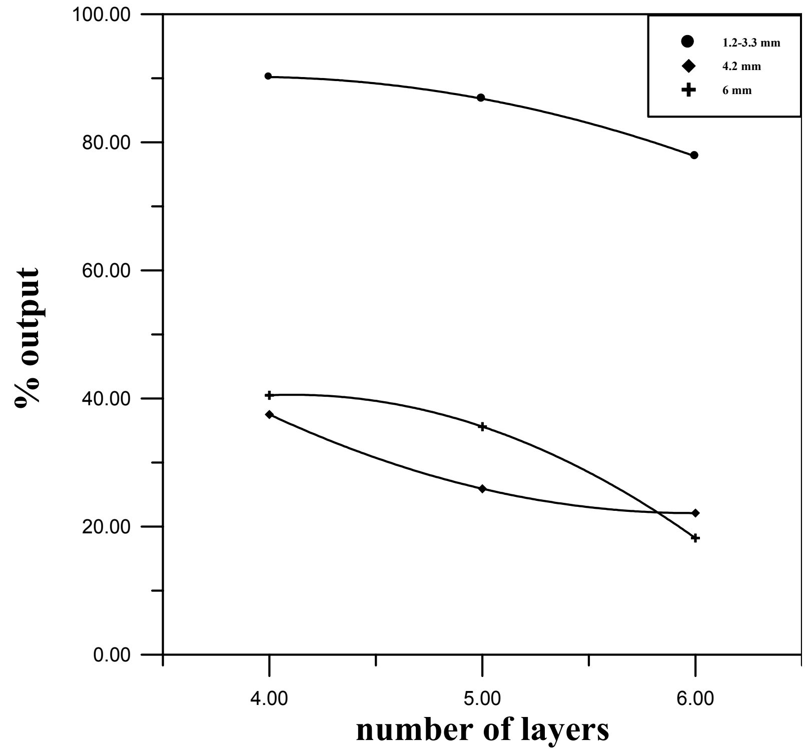


Fig. 4.37 number of layers vs. percent output for: N1=0.38, N2=0.29, N3=0.13, N4=0.2

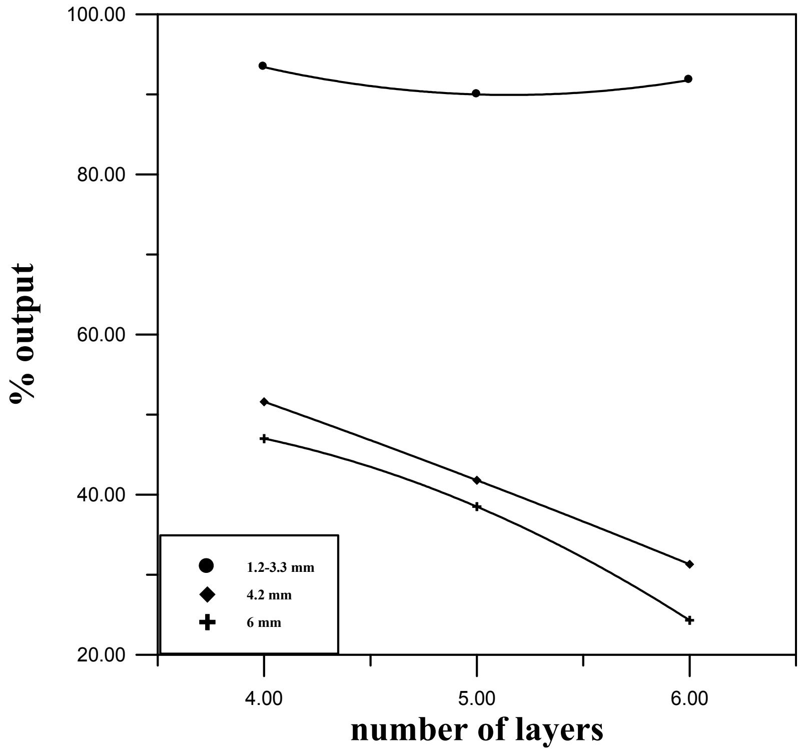


Fig. 4.38 number of layers vs. percent output for: N1=0.3, N2=0.2, N3=0.3, N4=0.2

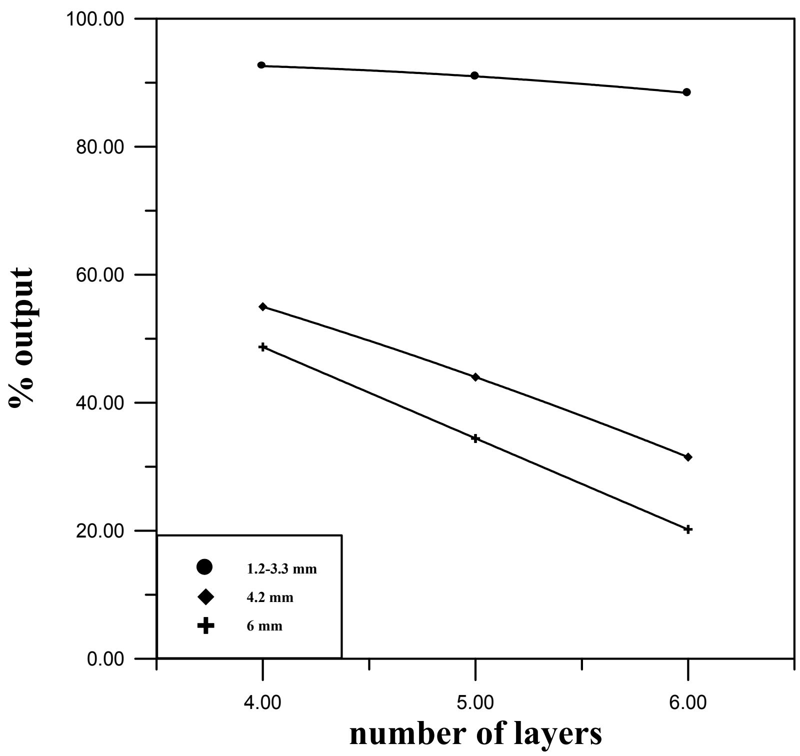


Fig. 4.39 number of layers vs. percent output for: N1=0.25, N2=0.35, N3=0.15, N4=0.25

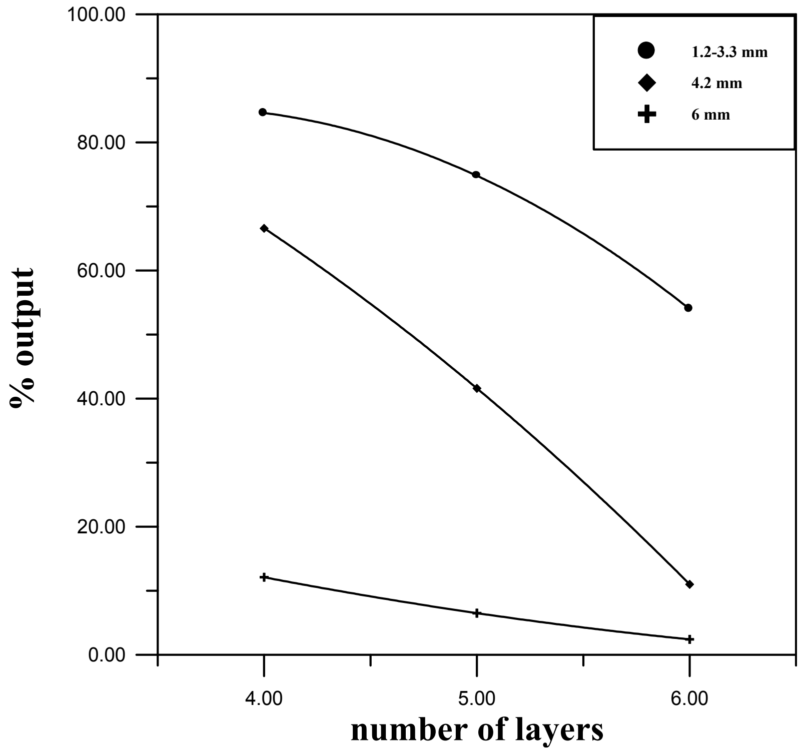


Fig. 4.40 number of layers vs. percent output for: N1=0.6, N2=0.18, N3=0.18, N4=0.03

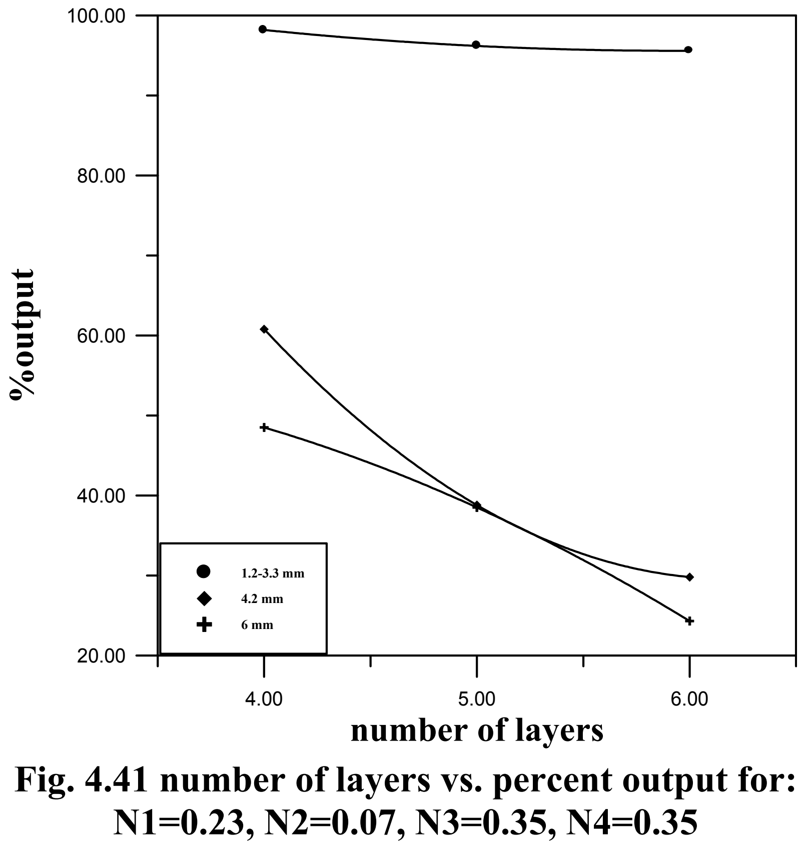


Fig. 4.41 number of layers vs. percent output for: N1=0.23, N2=0.07, N3=0.35, N4=0.35

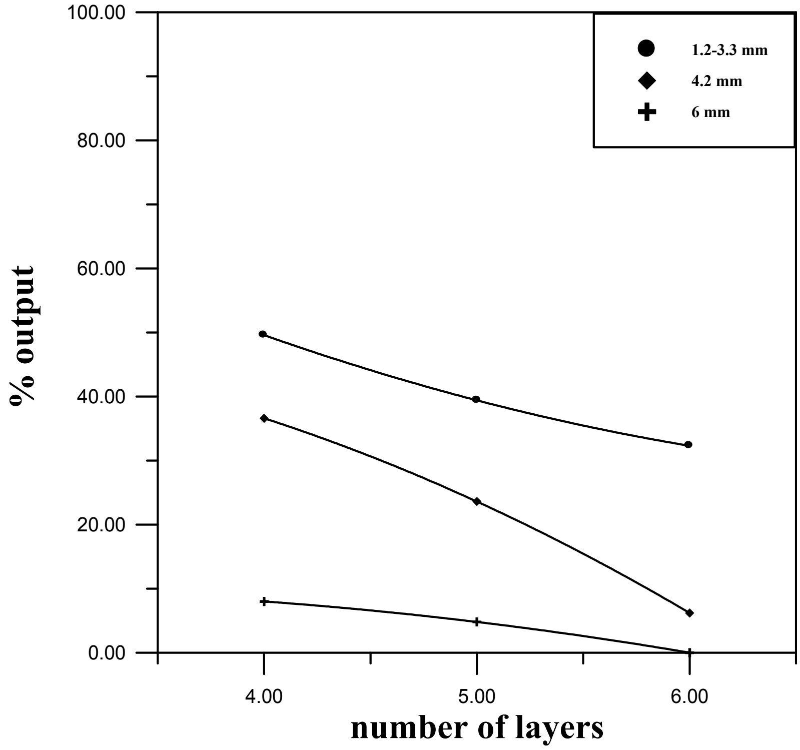


Fig. 4.42 number of layers vs. percent output for: N1=0.8, N2=0.04, N3=0.13, N4=0.03

Chapter Five

Conclusions and Recommendations For Future Work

5.1. Conclusions

1. From the theoretical part of this research, it was concluded that the probability of finding pore size in any packed bed is different for each kind of distribution.

2. the percent output of impurities, which passed through the packed bed decrease with increasing the number of layers; and also decrease with increasing the size of impurities ;but in case of 6 mm impurities it is increase not like the other cases and this make sure that the exist of bigger pores than the theoretical maximum pores, but the effect of these pores is reduce and disappear when increasing the number of layers, and the number of available pores for passing the first particle, which has volume of 6 mm and that will be more than the available particles for the smaller particles and that leading to increase the probability of configuration the bridge between the little particles and that will prohibit the little particles from passing through a good pores for passing particles as a speed not a pile.

3. Increasing the number of large spheres in the packed bed leads to increase the percent output of impurities and this in turn leads to increase the mean pore diameter (due to number, length, surface area, and volume), and increase the number of small or medium spheres leads to a reduction in the output of impurities and reduction in the mean pore diameter.

5.2. Recommendation for Future Work

1. Developing equations that give the relation between the probability and the diameter of the pores (d_C) for define types of distribution (RRSB, normal distribution).

2. Taking other types of packing and impurities with different composition, diameters, and layers to study the properties of the packing.

3. Choosing the distribution for the types of spheres which are used in the packing to increase the accuracy and this is achieved by using equations or graphs, and this kind of distribution helps to know best kinds of impurities that may be used to pass through the packing.

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Appendix A

Sample of calculation

As example for case of:

d_K=10.6 mm d_M=14.97mm d_G=20.89mm

And:

N_K=0.20 N_M=0.30 N_G=0.40

Diameter of the pores for three different sizes of spheres:

$$d_{C3} = \frac{K_4 - (K_4^{\ 2} - 4K_5)^{0.5}}{2} * d_g \qquad ...(2.1)$$

Where:

$$k_1 = \left[\frac{(a_m + 1)}{(a_m - 1)}\right]^2 \qquad k_2 = \frac{4a_m}{(a_m + 1)}$$

$$k_3 = \left(a_k^{\ 2} + a_k k_2\right)^{0.5} - a_k \qquad k_4 = \left(k_2 + 2k_3\right) * k_1$$

$$k_5 = k_3^{\ 2} * k_1$$

$$a_k = \frac{d_k}{d_g} \text{..........} \ .(<= 1) \qquad a_m = \frac{d_m}{d_g} \text{........(} \ = 1)$$

a_M=14.97/20.89=0.7166

a_K=10.6/20.89=0.5074

K_1= [(0.7166+1)/ (0.7166-1)] ^{2}=36.6892

K_2=4*0.7166/ (0.7166+1) =1.6698

K_3= (0.5074 ^{2} + (0.5074*1.6698)) $^{0.5}$ -0.5074= 0.5436

K_4= (1.6698+ (2*0.5436))*36.6892=101.1521

K5=0.5436 ^{2}*36.6892=10.8417

$$d_{c3} = [\frac{101.1521 - (101.1521^2 - 4*10.8417)^{0.5}}{2}]*20.89$$

=2.2414 mm.

$$p_i = \frac{3!}{n_g!n_m!n_k!} p_{r_{dg}}{}^{ng} * p_{r_{dm}}{}^{nm} * p_{r_{dk}}{}^{nk} \qquad ...(2.4)$$

Where r_g+r_m+r_k=3

N_k=1

N_m=1

N_g=1

$$p_3 = \frac{1*2*3}{1*1*1} * [(0.4)^1 * (0.3)^1 * (0.2)^1$$

=0.144

To calculate the mean pore diameter (dc_m) for packed bed consisting of the above number percent of sphere, using the following equation:

$$dc_m = \sum_{i=1}^{n} p_i dc_i$$

d_{Cm}=1.643*0.015625+1.822281*0.046875+1.982672*0.046875+2.044092 *0.046875+2.074898*0.046875+2.241816*0.09375+2.32035*0.015625 +2.356291*0.09375+2.481983*0.046875+2.564951*0.046875+2.623555* 0.09375+2.71303*0.046875+2.7828*0.046875+2.865761*0.046875+3.048275* 0.09375+3.23795*0.015625+3.251875*0.046875+3.456442*0.046875+ 3.710169*0.046875+4.0052*0.015625.

=2.626234.

Appendix B

Computer Program 1

```
10 REM ******************************************************
20 REM   *****pore size in packed bed of four sizes of spheres*****
30 REM ********************************************************
40 DEF fnz (a) = (((2*A+ A^2)^.5 - A ^2 /(2 + 2 * ((2 * a + a ^ 2) ^ .5 - a))) * dg
50 DEF fnq (a) =(((2/a+ a^-2)^ .5-a ^-1)^2 /(2 + 2*((2 /a +a ^-2) ^.5 -a  -1))) * dk
60 n = 0
70 s = 0
80 DIM d (4)
90 DIM dc (10)
100 DIM prz (10)
110 DIM pz (10)
120 DIM prl (10)
130 DIM Pl (10)
140 DIM pra (10)
150 DIM pa (10)
160 DIM prv(10)
170 DIM pv (10)
180 FOR j = 1 TO 4
190 READ d (j)
200 PRINT "diameter"; j; "="; d (j)
210 NEXT j
220 FOR i = 1 TO 2
230 IF d (i) < d (i + 1) THEN 240 ELSE 320
240 dg = d (i + 1)
250 dk = d (i)
260 ak = dk / dg
270 n = n + 1
280 dc (n) = fnz(ak)
290 n = n + 1
300 dc (n) = fnq(ak)
310 n = n + 1
320 IF i + 2 > 3 THEN 400
330 IF d (i) < d (i + 2) THEN 340
340 dk = d (i)
350 dg = d (i + 2)
```

```
360 ak = dk / dg
370 dc (n) = fnz(ak)
380 n = n + 1
390 dc (n) = fnq(ak)
400 NEXT i
410 FOR i = 1 TO 4
420 dc (i + 6) = .155 * d (i)
430 NEXT i
440 dk = d (1)
450 dm1 = d (2)
460 dm2 = d (3)
465 dg = d (4)
470 am = dm / dg
480 ak = dk / dg
490 k1 = ((am + 1) / (am - 1)) ^ 2
500 k2 = 4 * am / (am + 1)
510 k3 = (ak ^ 2 + ak * k2) ^ .5 - ak
520 k4 = (K2 + 2 * k3) * k1
530 k5 = k3 ^ 2 * k1
540 dc (10) = ((k4 - (k4 ^ 2 - 4 * k5) ^ .5) / 2) * dg
550 FOR i = 1 TO 20
560 FOR j = 1 TO 19
570 IF dc (i) > dc (j) THEN 610
580 x = dc (i)
590 dc (i) = dc (j)
600 dc (j) = x
610 NEXT j
620 NEXT i
630 FOR i = 1 TO 20
640 PRINT dc (i)
650 NEXT
660 PRINT: PRINT "****************************"
670 REM ***************************************************
680 REM ****calculating area, length and volume percent ****
690 REM ***************************************************
700 INPUT "zk="; zk
710 INPUT "zm1="; zm1
720 INPUT "zm2="; zm2
730 INPUT "zg="; zg
740 PRINT "zk="; zk
750 PRINT "zm1="; zm1
```

```
760 PRINT "zm2='; zm2"
770 PRINT "zg="; zg
780 l1 = (zk * d (1)) + (zm1 * d (2)) + (zm2 * d (3)) + (zg * d (4))
790 a1 = (zk * d (1) ^ 2) + (zm1 * d (2) ^ 2) + (zm2 * d (3) ^ 2) + (zg * d (4) ^ 2)
800 v1 = (zk * d (1) ^ 3) + (zm1 * d (2) ^ 3) + (zm2 * d (3) ^ 3) + (zg * d (4) ^ 3)
810 lk = (zk * d (1)) / l1
820 PRINT "lk="; lk
830 lm1 = (zm1 * d (2)) / l1
840 PRINT "lm1='; lm1"
850 lm2 = (zm2 * d (3)) / l1
860 PRINT "lm2="; lm2
870 lg = (zg * d (4)) / l1
880 PRINT "lg="; lg
890 ak = (zk * d (1) ^ 2) / a1
900 PRINT "ak="; ak
910 am1 = (zm1 * d (2) ^ 2) / a1
920 PRINT "am1="; am1
930 am2 = (zm2 * d (3) ^ 2) / a1
940 PRINT "am2="; am2
950 ag = (zg * d (4) ^ 2) / a1
960 PRINT "ag="; ag
970 vk = (zk * d (1) ^ 3) / v1
980 PRINT "vk=';vk"
990 vm1 = (zm1 * d (2) ^ 3) / v1
1000 PRINT "vm1="; vm1
1010 vm2 = (zm2 * d (3) ^ 3) / v1
1020 PRINT "vm2="; vm2
1030 vg = (zg * d (4) ^ 3) / v1
1040 PRINT "vg="; vg
1050 PRINT "****************************************"
1060 REM ############################################################
1070 REM ################## probability calculation ##################
1080 REM ############################################################
1090 PRINT TAB(1);"pz(w)";TAB(20); "pl(w)"; TAB(40); "; pa(w); "; pv(w); ""
1100 PRINT TAB(1); "------";TAB(20); "------";TAB(40); "------";TAB(60)
1110 nk = 3
1120 nm1 = 0
1130 nm2 = 0
1140 ng = 0
1150 GOSUB 2550
1160 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
```

```
1170 nk = 0
1180 nm1 = 3
1190 nm2 = 0
1200 nm3 = 0
1210 ng = 0
1220 GOSUB 2550
1230 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1240 nk = 0
1250 nm1 = 0
1260 nm2 = 3
1270 ng = 0
1280 GOSUB 2550
1290 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1300 nk = 0
1310 nm1 = 0
1320 nm2 = 0
1330 ng = 3
1340 GOSUB 2550
1350 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1360 nk = 1
1370 nm1 = 1
1380 nm2 = 1
1390 ng = 0
1400 GOSUB 2550
1410 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1420 nk = 1
1430 nm1 = 0
1440 nm2 = 1
1450 ng = 1
1460 GOSUB 2550
1470 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1480 nk = 1
1490 nm1 = 1
1500 nm2 = 0
1510 ng = 1
1520 GOSUB 2550
1530 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1540 nk = 0
1550 nm1 = 1
1560 nm2 = 1
1570 ng = 1
```

```
1580 GOSUB 2550
1590 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1600 nk = 1
1610 nm1 = 2
1620 nm2 = 0
1630 ng = 0
1640 GOSUB 2550
1650 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1660 nk = 1
1670 nm1 = 0
1680 nm2 = 2
1690 ng = 0
1700 GOSUB 2550
1710 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1720 nk = 1
1730 nm1 = 0
1740 nm2 = 0
1750 ng = 2
1760 GOSUB 2550
1770 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1780 nk = 0
1790 nm1 = 1
1800 nm2 = 2
1810 ng = 0
1820 GOSUB 2550
1830 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1840 nk = 0
1850 nm1 = 1
1860 nm2 = 0
1870 ng = 2
1880 GOSUB 2550
1890 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1900 nk = 0
1910 nm1 = 0
1920 nm2 = 1
1930 ng = 2
1940 GOSUB 2550
1950 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
1960 nk = 2
1970 nm1 = 1
1980 nm2 = 0
```

```
1990 ng = 0
2000 GOSUB 2550
2010 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
2020 nk = 2
2030 nm1 = 0
2040 nm2 = 1
2050 ng = 0
2060 GOSUB 2550
2070 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
2080 nk = 0
2090 nm1 = 2
2100 nm2 = 1
2110 ng = 0
2120 GOSUB 2550
2130 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
2140 nk = 2
2150 nm1 = 0
2160 nm2 = 0
2170 ng = 1
2180 GOSUB 2550
2190 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
2200 nk = 0
2210 nm1 = 2
2220 nm2 = 0
2230 ng = 1
2240 GOSUB 2550
2250 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
2260 nk = 0
2270 nm1 = 0
2280 nm2 = 2
2290 ng = 1
2300 GOSUB 2550
2310 PRINT TAB(1); pz(w); TAB(20); pl(w); TAB(40); pa(w); TAB(60); pv(w)
2320 PRINT "--------------------------------------------------"
2330 FOR q = 1 TO 20
2340 dz = dz + (prz (q) * dc (q))
2350 NEXT q
2360 PRINT "mean diameter due to number="; dz
2370 FOR q = 1 TO 20
2380 dl = dl + (prl (q) * dc (q))
2390 NEXT q
```

```
2400 PRINT "mean diameter due to length="; dl
2410 FOR q = 1 TO 20
2420 da = da + (pra (q) * d (q))
2430 NEXT q
2440 PRINT "mean diameter due to area="; da
2450 FOR q = 1 TO 20
2460 dv = dv + (prv (q) * d (q))
2470 NEXT q
2480 PRINT "mean diameter due to volume="; dv
2490 PRINT "____________________________________________________________"
2500 DATA 10.6, 14.97, 20.89, 25.84
2510 END
2520 REM ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2530 REM ^^^^^^^^^^^^^^^^^^^^^^^^ subroten^^^^^^^^^^^^^^^^^^^^
2540 REM ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2550 w = w + 1
2560 f1 = 1
2570 FOR i = 1 TO nk
2580 f1 = f1 * i
2590 NEXT i
2600 f2 = 1
2610 FOR i = 1 TO nm1
2620 f2 = f2 * i
2630 NEXT i
2640 f3 = 1
2650 FOR i=1 to nm2
2670 f3=f3*i
2680 f4=1
2690 FOR i=1 to ng
2700 f4=f4*i
2710 end
```

Computer Program 2

```
10 D1=10.6:D2=14.97:D3=20.89:D4=25.84
20 INPUT AK: INPUT AM1: INPUT AM2: INPUT AG
30 Z1=AK/D1^2+AM1/D2^2+AM2/D3^2+AG/D4^2
40 ZK= (AK/D1^2)/Z1: PRINT ZK
50 ZM1= (AM1/D2^2)/Z1: PRINT ZM1
60 ZM2= (AM2/D3^2)/Z1: PRINT ZM2
70 ZG= (AG/D4^2)/Z1: PRINT ZG
```

Computer Program 3

```
10 D1=10.6: D2=14.97: D3=20.89: D4=25.84
20 INPUT LK: INPUT LM1: INPUT LM2: INPUT LG
30 Z1=LK/D1+LM1/D2+LM2/D3+LG/D4
40 ZK= (LK/D1)/Z1: PRINT ZK
50 ZM1= (LM1/D2)/Z1: PRINT ZM1
60 ZM2= (LM2/D3)/Z1: PRINT ZM2
70 ZG= (LG/D4)/Z1: PRINT ZG
```

Computer Program 4

```
10 D1=10.6: D2=14.97: D3=20.89: D4=25.84
20 INPUT VK: INPUT VM1: INPUT VM2: INPUT VG
30 Z1=VK/D1^3+VM1/D2^3+VM2/D3^3+VG/D4^3
40 ZK= (VK/D1^3)/Z1: PRINT ZK
50 ZM1= (VM1/D2^3)/Z1: PRINT ZM1
60 ZM2= (VM2/D3^3)/Z1: PRINT ZM2
70 ZG= (VG/D4^3)/Z1: PRINT ZG
```

Appendix C

Results obtained from computer program

Table C-1 Results obtained by computer program
For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.25	L_1=0.15	A_1=0.08	V_1=0.04
N_2=0.25	L_2=0.20	A_2=0.16	V_2=0.11
N_3=0.25	L_3=0.29	A_3=0.30	V_3=0.30
N_4=0.25	L_4=0.36	A_4=0.46	V_4=0.55

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.000064	0.003375	0.000512	0.000064
1.822281	0.000592	0.016875	0.003584	0.000592
1.982672	0.002032	0.03645	0.009344	0.002032
2.044092	0.003484	0.05445	0.015488	0.003484
2.074898	0.006124	0.07875	0.02432	0.006124
2.241816	0.014044	0.13095	0.04736	0.014044
2.32035	0.015375	0.13895	0.051456	0.015375
2.356291	0.029895	0.20375	0.086784	0.029895
2.481983	0.040695	0.241595	0.108384	0.040695
2.564951	0.051585	0.276395	0.131424	0.051585
2.623555	0.091185	0.370355	0.197664	0.091185
2.71303	0.11115	0.413555	0.232992	0.11115
2.7828	0.14745	0.471875	0.283776	0.14745
2.865761	0.17715	0.522335	0.326976	0.17715
3.048275	0.28605	0.647615	0.459456	0.28605
3.23795	0.31305	0.672004	0.486456	0.31305
3.251875	0.412875	0.749764	0.588024	0.412875
3.456442	0.561375	0.840592	0.712224	0.561375
3.710169	0.833625	0.953344	0.902664	0.833625
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-2 Results obtained by computer program

For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.20	L_1=0.12	A_1=0.07	V_1=0.04
N_2=0.30	L_2=0.26	A_2=0.20	V_2=0.15
N_3=0.40	L_3=0.47	A_3=0.53	V_3=0.55
N_4=0.10	L_4=0.15	A_4=0.20	V_4=0.26

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.008	0.001762	0.000313	4.66617E-05
1.822281	0.044	0.012963	0.003121	0.000638116
1.982672	0.092	0.033802	0.010411	0.002781056
2.044092	0.146	0.057529	0.018811	0.005280022
2.074898	0.158	0.063973	0.0216	0.006293962
2.241816	0.302	0.152266	0.065221	0.024402317
2.32035	0.329	0.16902	0.073598	0.027921794
2.356291	0.365	0.196323	0.090283	0.036489829
2.481983	0.461	0.278462	0.146912	0.06929465
2.564951	0.569	0.371981	0.212163	0.107549639
2.623555	0.617	0.422782	0.255485	0.138593082
2.71303	0.644	0.451702	0.280445	0.15669357
2.7828	0.65	0.459557	0.288731	0.16403773
2.865761	0.794	0.633559	0.458148	0.302642039
3.048275	0.866	0.741176	0.587758	0.433804315
3.23795	0.93	0.849093	0.734384	0.601199952
3.251875	0.939	0.865732	0.759172	0.632229909
3.456442	0.987	0.965849	0.927432	0.86984149
3.710169	0.999	0.995849	0.991793	0.982268283
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-3 Results obtained by computer program

For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.42	L_1=0.28	A_1=0.17	V_1=0.09
N_2=0.25	L_2=0.23	A_2=0.20	V_2=0.15
N_3=0.18	L_3=0.24	A_3=0.28	V_3=0.30
N_4=0.15	L_4=0.25	A_4=0.35	V_4=0.46

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.074088	0.021952	0.004913	0.000729
1.822281	0.206388	0.076048	0.022253	0.004374
1.982672	0.301644	0.132496	0.046529	0.011664
2.044092	0.380394	0.176932	0.066929	0.017739
2.074898	0.459774	0.235732	0.097274	0.028917
2.241816	0.573174	0.328468	0.154394	0.053217
2.32035	0.588799	0.340635	0.162394	0.056592
2.356291	0.683299	0.437235	0.233794	0.093852
2.481983	0.724123	0.485619	0.273778	0.118152
2.564951	0.757873	0.523707	0.307378	0.138402
2.623555	0.825913	0.624507	0.407338	0.212922
2.71303	0.854038	0.664182	0.449338	0.243972
2.7828	0.882388	0.716682	0.511813	0.301104
2.865761	0.906688	0.756426	0.558853	0.341604
3.048275	0.947188	0.839226	0.676453	0.465804
3.23795	0.95302	0.85305	0.698405	0.492804
3.251875	0.969895	0.896175	0.771905	0.588024
3.456442	0.984475	0.939375	0.854225	0.712224
3.710169	0.996625	0.984375	0.957125	0.902664
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-4 Results obtained by computer program

For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.50	L_1=0.38	A_1=0.26	V_1=0.16
N_2=0.34	L_2=0.36	A_2=0.35	V_2=0.31
N_3=0.10	L_3=0.15	A_3=0.20	V_3=0.25
N_4=0.06	L_4=0.11	A_4=0.19	V_4=0.28

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.125	0.054872	0.017576	0.004096
1.822281	0.38	0.210824	0.088556	0.027904
1.982672	0.455	0.275804	0.129116	0.047104
2.044092	0.6284	0.423548	0.224666	0.093232
2.074898	0.6734	0.4712	0.263198	0.114736
2.241816	0.7754	0.59432	0.372398	0.189136
2.32035	0.814704	0.640976	0.415273	0.218927
2.356291	0.875904	0.731264	0.519013	0.302255
2.481983	0.890904	0.756914	0.550213	0.332255
2.564951	0.925584	0.815234	0.623713	0.40433
2.623555	0.943584	0.852854	0.682993	0.47153
2.71303	0.964392	0.895622	0.752818	0.552254
2.7828	0.969792	0.909416	0.780976	0.589886
2.865761	0.987704	0.933716	0.822976	0.648011
3.048275	0.989944	0.969356	0.902776	0.778211
3.23795	0.990944	0.972731	0.910776	0.793836
3.251875	0.994944	0.985799	0.948681	0.866748
3.456442	0.996744	0.993224	0.971481	0.919248
3.710169	0.999744	0.998669	0.993141	0.978048
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-5 Results obtained by computer program

For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.38	L_1=0.25	A_1=0.14	V_1=0.07
N_2=0.29	L_2=0.26	A_2=0.22	V_2=0.16
N_3=0.13	L_3=0.17	A_3=0.20	V_3=0.20
N_4=0.20	L_4=0.32	A_4=0.44	V_4=0.57

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.054872	0.015625	0.002744	0.000343
1.822281	0.1805	0.064375	0.01568	0.002695
1.982672	0.236816	0.09625	0.02744	0.005635
2.044092	0.33269	0.14695	0.047768	0.011011
2.074898	0.41933	0.20695	0.07364	0.01939
2.241816	0.505286	0.27325	0.1106	0.03283
2.32035	0.529675	0.290826	0.121248	0.036926
2.356291	0.661915	0.415626	0.20256	0.07523
2.481983	0.681181	0.437301	0.21936	0.08363
2.564951	0.71398	0.471777	0.2484	0.09899
2.623555	0.77326	0.553377	0.32232	0.14687
2.71303	0.82372	0.618273	0.386208	0.190646
2.7828	0.86932	0.695073	0.46752	0.258875
2.865761	0.884023	0.717615	0.49392	0.278075
3.048275	0.929263	0.802479	0.61008	0.387515
3.23795	0.93146	0.807392	0.61808	0.395515
3.251875	0.96626	0.887264	0.745856	0.551467
3.456442	0.9764	0.915008	0.798656	0.619867
3.710169	0.992	0.967232	0.914816	0.814807
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-6 Results obtained by computer program

For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.30	L_1=0.18	A_1=0.10	V_1=0.05
N_2=0.20	L_2=0.17	A_2=0.13	V_2=0.09
Nn_3=0.30	L_3=0.36	A_3=0.38	V_3=0.38
N_4=0.20	L_4=0.29	A_4=0.39	V_4=0.48

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.000125	0.001	0.005832	0.027
1.822281	0.0008	0.0049	0.022356	0.081
1.982672	0.00365	0.0163	0.057348	0.162
2.044092	0.004865	0.02137	0.072954	0.198
2.074898	0.008465	0.03307	0.101142	0.252
2.241816	0.018725	0.06271	0.167238	0.36
2.32035	0.019454	0.064907	0.172151	0.368
2.356291	0.032414	0.095327	0.225395	0.44
2.481983	0.054074	0.138647	0.295379	0.521
2.564951	0.063308	0.157913	0.326591	0.557
2.623555	0.118028	0.246833	0.439343	0.665
2.71303	0.129692	0.266606	0.464486	0.689
2.7828	0.164252	0.312236	0.5099	0.725
2.865761	0.20324	0.368552	0.575996	0.779
3.048275	0.301736	0.484148	0.682484	0.851
3.23795	0.356608	0.53902	0.72914	0.878
3.251875	0.418816	0.598339	0.772031	0.902
3.456442	0.626752	0.767287	0.884783	0.956
3.710169	0.889408	0.940681	0.975611	0.992
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-7 Results obtained by computer program

For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.25	L_1=0.15	A_1=0.08	V_1=0.04
N_2=0.35	L_2=0.30	A_2=0.23	V_2=0.16
N_3=0.15	L_3=0.18	A_3=0.19	V_3=0.20
N_4=0.25	L_4=0.37	A_4=0.50	V_4=0.60

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.0625	0.003375	0.000512	0.000064
1.822281	0.128125	0.023625	0.004928	0.000832
1.982672	0.15625	0.035775	0.008576	0.001792
2.044092	0.248125	0.076275	0.021272	0.004864
2.074898	0.295	0.10125	0.030872	0.007744
2.241816	0.37375	0.14985	0.051848	0.015424
2.32035	0.49625	0.17685	0.064015	0.01952
2.356291	0.6275	0.27675	0.119215	0.04256
2.481983	0.644375	0.29133	0.127879	0.04736
2.564951	0.6995	0.33993	0.158032	0.06272
2.623555	0.75575	0.39987	0.203632	0.09152
2.71303	0.847625	0.49977	0.282982	0.1376
2.7828	0.8945	0.561375	0.342982	0.1808
2.865761	0.918125	0.590535	0.367891	0.2
3.048275	0.996875	0.710415	0.498991	0.3152
3.23795	0.99725	0.716247	0.50585	0.3232
3.251875	0.997813	0.839457	0.67835	0.496
3.456442	0.997981	0.875421	0.7325	0.568
3.710169	0.998111	0.949347	0.875	0.784
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-8 Results obtained by computer program

For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.60	L_1=0.46	A_1=0.32	V_1=0.20
N_2=0.18	L_2=0.20	A_2=0.20	V_2=0.18
N_3=0.18	L_3=0.28	A_3=0.38	V_3=0.47
N_4=0.03	L_4=0.06	A_4=0.10	V_4=0.15

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.216	0.097336	0.032768	0.04
1.822281	0.4104	0.224296	0.094208	0.0616
1.982672	0.6048	0.40204	0.210944	0.118
2.044092	0.66312	0.45724	0.249344	0.13744
2.074898	0.69552	0.495328	0.280064	0.15544
2.241816	0.81216	0.649888	0.425984	0.25696
2.32035	0.817992	0.657888	0.433984	0.28936
2.356291	0.837432	0.691008	0.472384	0.32176
2.481983	0.895752	0.7992	0.611008	0.4543
2.564951	0.913248	0.8328	0.656608	0.499984
2.623555	0.932688	0.879168	0.729568	0.584584
2.71303	0.935604	0.886368	0.741568	0.599164
2.7828	0.937224	0.891336	0.751168	0.612664
2.865761	0.95472	0.938376	0.837808	0.73195
3.048275	0.960552	0.958536	0.883408	0.80809
3.23795	0.966384	0.980488	0.93828	0.83018
3.251875	0.971244	0.982648	0.94428	0.84233
3.456442	0.974244	0.99676	0.9876	0.941735
3.710169	0.979104	0.999784	0.999	0.97346
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-9 Results obtained by computer program

For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.23	L_1=0.12	A_1=0.06	V_1=0.03
N_2=0.07	L_2=0.05	A_2=0.04	V_2=0.02
N_3=0.35	L_3=0.37	A_3=0.35	V_3=0.33
N_4=0.35	L_4=0.46	A_4=0.55	V_4=0.62

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.012167	0.001728	0.000216	0.000027
1.822281	0.023276	0.003888	0.000648	0.000081
1.982672	0.078821	0.019872	0.004428	0.000972
2.044092	0.082202	0.020772	0.004716	0.001008
2.074898	0.137747	0.040644	0.010656	0.002682
2.241816	0.171557	0.053964	0.015696	0.00387
2.32035	0.1719	0.054089	0.01576	0.003878
2.356291	0.20571	0.070649	0.02368	0.00611
2.481983	0.290235	0.119933	0.04573	0.015911
2.564951	0.29538	0.122708	0.04741	0.016307
2.623555	0.46443	0.245252	0.11671	0.053135
2.71303	0.469575	0.248702	0.11935	0.053879
2.7828	0.5541	0.324878	0.1738	0.088475
2.865761	0.579825	0.345413	0.1885	0.095009
3.048275	0.631275	0.396473	0.2347	0.119561
3.23795	0.67415	0.447126	0.277575	0.155498
3.251875	0.699875	0.478866	0.313875	0.178562
3.456442	0.8285	0.667788	0.516	0.381116
3.710169	0.957125	0.902664	0.833625	0.761672
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-10 Results obtained by computer program

For: d1=10.6, d2=14.97, d3=20.89, d4=25.84

N_1=0.80	L_1=0.67	A_1=0.51	V_1=0.34
N_2=0.04	L_2=0.05	A_2=0.05	V_2=0.05
N_3=0.13	L_3=0.22	A_3=0.33	V_3=0.42
N_4=0.03	L_4=0.06	A_4=0.11	V_4=0.19

Diameter of The pores (dc) (mm)	Probability Due to number(pr_N)	Probability Due to Length (pr_L)	Probability Due to Area (pr_A)	Probability Due to Volume(pr_V)
1.643	0.512	0.300763	0.132651	0.039304
1.822281	0.5888	0.368098	0.171666	0.056644
1.982672	0.8384	0.664372	0.429165	0.2023
2.044092	0.84224	0.669397	0.43299	0.20485
2.074898	0.89984	0.750199	0.518823	0.270742
2.241816	0.9248	0.794419	0.569313	0.313582
2.32035	0.924864	0.794544	0.569438	0.313707
2.356291	0.930624	0.806604	0.586268	0.333087
2.481983	0.971184	0.903888	0.752885	0.513015
2.564951	0.971808	0.905538	0.75536	0.516165
2.623555	0.990528	0.958602	0.866438	0.678957
2.71303	0.990672	0.959052	0.867263	0.680382
2.7828	0.992832	0.966288	0.885776	0.717204
2.865761	0.99486	0.973548	0.902111	0.743664
3.048275	0.995796	0.977508	0.913001	0.767604
3.23795	0.997993	0.988156	0.948938	0.841692
3.251875	0.998101	0.988696	0.965273	0.847107
3.456442	0.999622	0.997408	0.968867	0.947655
3.710169	0.999973	0.999784	0.979648	0.993141
4.0052	1	1	1	1

Note: all diameters above are in (mm).

Table C-11 Values of mean pore diameters for:
d1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.25, N_2=0.25, N_3=0.25, N_4=0.25

Mean pore diameter due to number	2.626234
Mean pore diameter due to length	2.931107
Mean pore diameter due to area	3.187854
Mean pore diameter due to volume	3.400090658

Table C-12 Values of mean pore diameters for:
d1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.20, N_2=0.30, N_3=0.40, N_4=0.10

Mean pore diameter due to number	2.593733
Mean pore diameter due to length	2.809225
Mean pore diameter due to area	3.001148
Mean pore diameter due to volume	3.161479852

Table C-13 Values of mean pore diameters for:
d1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.42, N_2=0.25, N_3=0.18, N_4=0.15

Mean pore diameter due to number	2.287938
Mean pore diameter due to length	2.589268
Mean pore diameter due to area	2.884202
Mean pore diameter due to volume	3.176426

Note: all diameters above are in (mm).

**Table C-14 Values of mean pore diameters for:
D1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.50, N_2=0.34, N_3=0.10, N_4=0.06**

Mean pore diameter due to number	2.068311
Mean pore diameter due to length	2.250333
Mean pore diameter due to area	2.491339
Mean pore diameter due to volume	2.757407

**Table C-15 Values of mean pore diameters for:
D1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.38, N_2=0.29, N_3=0.13, N_4=0.20**

Mean pore diameter due to number	2.343921
Mean pore diameter due to length	2.655236
Mean pore diameter due to area	2.981324
Mean pore diameter due to volume	3.28652

**Table C-16 Values of mean pore diameters for:
D1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.30, N_2=0.20, N_3=0.30, N_4=0.20**

Mean pore diameter due to number	2.553293
Mean pore diameter due to length	2.857608
Mean pore diameter due to area	3.129254
Mean pore diameter due to volume	3.349192

Note: all diameters above are in (mm).

Table C-17 Values of mean pore diameters for:
D1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.25, N_2=0.35, N_3=0.15, N_4=0.25

Mean pore diameter due to number	2.363133
Mean pore diameter due to length	2.838704
Mean pore diameter due to area	3.138726
Mean pore diameter due to volume	3.378172

Table C-18 Values of mean pore diameters for:
D1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.60, N_2=0.18, N_3=0.18, N_4=0.03

Mean pore diameter due to number	2.069578
Mean pore diameter due to length	2.223594
Mean pore diameter due to area	2.467871
Mean pore diameter due to volume	2.670886

Table C-19 Values of mean pore diameters for:
D1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.23, N_2=0.07, N_3=0.35, N_4=0.35

Mean pore diameter due to number	2.891019
Mean pore diameter due to length	3.21899
Mean pore diameter due to area	3.434463
Mean pore diameter due to volume	3.585175863

Note: all diameters above are in (mm).

Table C-20 Values of mean pore diameters for:
D1=10.6, d2=14.97, d3=20.89, d4=25.84
N_1=0.80, N_2=0.04, N_3=0.13, N_4=0.03

Mean pore diameter due to number	1.853664
Mean pore diameter due to length	2.025205
Mean pore diameter due to area	2.287116
Mean pore diameter due to volume	2.607051524

Table C-21 Values of percent output of impurities for each Mean Pore diameter due to number (four layers)

Dc_m n (mm)	N1	N2	N3	N4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
1.853664	0.8	0.04	0.13	0.03	49.6	36.6	8
2.068311	0.5	0.34	0.1	0.06	89.6	48.5	24.3
2.069578	0.6	0.18	0.18	0.03	84.6	66.6	12.1
2.287938	0.42	0.25	0.18	0.15	91	32	34.8
2.343921	0.38	0.29	0.13	0.2	90.2	37.5	40.5
2.363133	0.25	0.35	0.15	0.25	92.6	55	48.7
2.553293	0.3	0.2	0.3	0.2	93.4	51.6	47
2.593733	0.2	0.3	0.4	0.1	93.2	60.3	48.5
2.626234	0.25	0.25	0.25	0.25	94	36.67	68.4
2.891019	0.23	0.07	0.35	0.35	98.2	60.8	48.5

Table C-22 Values of percent output of impurities for each Mean Pore diameter due to number (five layers)

Dc_m n (mm)	N1	N2	N3	N4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
1.853664	0.8	0.04	0.13	0.03	39.4	23.6	4.8
2.068311	0.5	0.34	0.1	0.06	70	27.5	18.2
2.069578	0.6	0.18	0.18	0.03	74.8	41.6	6.5
2.287938	0.42	0.25	0.18	0.15	81.6	18.8	22.6
2.343921	0.38	0.29	0.13	0.2	86.8	25.9	35.6
2.363133	0.25	0.35	0.15	0.25	91	44	34.4
2.553293	0.3	0.2	0.3	0.2	90	41.8	38.5
2.593733	0.2	0.3	0.4	0.1	89.6	30.5	36.4
2.626234	0.25	0.25	0.25	0.25	91.6	33.3	45.3
2.891019	0.23	0.07	0.35	0.35	96.2	38.8	38.5

Table C-23 Values of percent output of impurities for each Mean Pore diameter due to number (six layers)

Dc_m n (mm)	N1	N2	N3	N4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
1.853664	0.8	0.04	0.13	0.03	32.3	6.2	0
2.068311	0.5	0.34	0.1	0.06	62	16.3	7.7
2.069578	0.6	0.18	0.18	0.03	54	11	2.4
2.287938	0.42	0.25	0.18	0.15	79.6	10	15.4
2.343921	0.38	0.29	0.13	0.2	77.8	22.1	18.2
2.363133	0.25	0.35	0.15	0.25	88.4	31.5	20.2
2.553293	0.3	0.2	0.3	0.2	91.8	31.3	24.3
2.593733	0.2	0.3	0.4	0.1	81.2	30.1	34.4
2.626234	0.25	0.25	0.25	0.25	88.4	24.1	30.3
2.891019	0.23	0.07	0.35	0.35	95.6	29.8	24.3

Table C-24 Values of percent output of impurities for each Mean Pore diameter due to length (four layers)

Dc_m l (mm)	L1	L2	L3	L4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
2.025205	0.67	0.05	0.22	0.06	49.6	36.6	8
2.223594	0.46	0.2	0.28	0.06	84.6	66.6	12.1
2.250333	0.38	0.36	0.15	0.11	89.6	48.5	24.3
2.589268	0.28	0.23	0.24	0.25	91	32	34.8
2.655236	0.25	0.26	0.17	0.32	90.2	37.5	40.5
2.809225	0.12	0.26	0.47	0.15	93.2	60.3	48.5
2.838704	0.15	0.3	0.18	0.37	92.6	55	48.7
2.857608	0.18	0.17	0.36	0.29	93.4	51.6	47
2.931107	0.15	0.2	0.29	0.36	94	36.67	68.4
3.21899	0.12	0.05	0.37	0.46	98.2	60.8	48.5

Table C-25 Values of percent output of impurities for each Mean Pore diameter due to length (five layers)

Dc_m l (mm)	L1	L2	L3	L4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
2.025205	0.67	0.05	0.22	0.06	39.4	23.6	4.8
2.223594	0.46	0.2	0.28	0.06	74.8	41.6	6.5
2.250333	0.38	0.36	0.15	0.11	70	27.5	18.2
2.589268	0.28	0.23	0.24	0.25	81.6	18.8	22.6
2.655236	0.25	0.26	0.17	0.32	86.8	25.9	35.6
2.809225	0.12	0.26	0.47	0.15	89.6	30.5	36.4
2.838704	0.15	0.3	0.18	0.37	91	44	34.4
2.857608	0.18	0.17	0.36	0.29	90	41.8	38.5
2.931107	0.15	0.2	0.29	0.36	91.6	33.3	45.3
3.21899	0.12	0.05	0.37	0.46	96.2	38.8	38.5

Table C-26 Values of percent output of impurities for each Mean Pore diameter due to length (six layers)

Dc_m l (mm)	L1	L2	L3	L4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
2.025205	0.67	0.05	0.22	0.06	32.3	6.2	0
2.223594	0.46	0.2	0.28	0.06	54	11	2.4
2.250333	0.38	0.36	0.15	0.11	62	16.3	7.7
2.589268	0.28	0.23	0.24	0.25	79.6	10	15.4
2.655236	0.25	0.26	0.17	0.32	77.8	22.1	18.2
2.809225	0.12	0.26	0.47	0.15	81.2	30.1	34.4
2.838704	0.15	0.3	0.18	0.37	88.4	31.5	20.2
2.857608	0.18	0.17	0.36	0.29	91.8	31.3	24.3
2.931107	0.15	0.2	0.29	0.36	88.4	24.1	30.3
3.21899	0.12	0.05	0.37	0.46	95.6	29.8	24.3

Table C-27 Values of percent output of impurities for each Mean Pore diameter due to area (four layers)

Dc_m a (mm)	A1	A2	A3	A4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
2.287116	0.51	0.05	0.33	0.11	49.6	36.6	8
2.467871	0.32	0.2	0.38	0.1	84.6	66.6	12.1
2.491339	0.26	0.35	0.2	0.19	89.6	48.5	24.3
2.884202	0.17	0.2	0.28	0.35	91	32	34.8
2.981324	0.14	0.22	0.2	0.44	90.2	37.5	40.5
3.001148	0.07	0.2	0.53	0.2	93.2	60.3	48.5
3.129254	0.1	0.13	0.38	0.39	93.4	51.6	47
3.187854	0.08	0.16	0.3	0.46	94	36.67	68.4
3.187854	0.08	0.23	0.19	0.5	92.6	55	48.7
3.434463	0.06	0.04	0.35	0.55	98.2	60.8	48.5

Table C-28 Values of percent output of impurities for each Mean Pore diameter due to area (five layers)

Dc_m a (mm)	A1	A2	A3	A4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
2.287116	0.51	0.05	0.33	0.11	39.4	23.6	4.8
2.467871	0.32	0.2	0.38	0.1	74.8	41.6	6.5
2.491339	0.26	0.35	0.2	0.19	70	27.5	18.2
2.884202	0.17	0.2	0.28	0.35	81.6	18.8	22.6
2.981324	0.14	0.22	0.2	0.44	86.8	25.9	35.6
3.001148	0.07	0.2	0.53	0.2	89.6	30.5	36.4
3.129254	0.1	0.13	0.38	0.39	90	41.8	38.5
3.187854	0.08	0.16	0.3	0.46	91.6	33.3	45.3
3.187854	0.08	0.23	0.19	0.5	91	44	34.4
3.434463	0.06	0.04	0.35	0.55	96.2	38.8	38.5

Table C-29 Values of percent output of impurities for each Mean Pore diameter due to area (six layers)

Dc_m a (mm)	A1	A2	A3	A4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
2.287116	0.51	0.05	0.33	0.11	32.3	6.2	0
2.467871	0.32	0.2	0.38	0.1	54	11	2.4
2.491339	0.26	0.35	0.2	0.19	62	16.3	7.7
2.884202	0.17	0.2	0.28	0.35	79.6	10	15.4
2.981324	0.14	0.22	0.2	0.44	77.8	22.1	18.2
3.001148	0.07	0.2	0.53	0.2	81.2	30.1	34.4
3.129254	0.1	0.13	0.38	0.39	91.8	31.3	24.3
3.187854	0.08	0.16	0.3	0.46	88.4	24.1	30.3
3.187854	0.08	0.23	0.19	0.5	88.4	31.5	20.2
3.434463	0.06	0.04	0.35	0.55	95.6	29.8	24.3

Table C-30 Values of percent output of impurities for each Mean Pore diameter due to volume (four layers)

Dc_m v (mm)	V1	V2	V3	V4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
2.607051	0.34	0.05	0.42	0.19	49.6	36.6	8
2.670886	0.2	0.18	0.47	0.15	84.6	66.6	12.1
2.757407	0.16	0.31	0.25	0.28	89.6	48.5	24.3
3.16148	0.04	0.15	0.55	0.26	93.2	60.3	48.5
3.176426	0.09	0.15	0.3	0.46	91	32	34.8
3.28652	0.07	0.16	0.2	0.57	90.2	37.5	40.5
3.349192	0.05	0.09	0.38	0.48	93.4	51.6	47
3.378172	0.04	0.16	0.2	0.6	92.6	55	48.7
3.400091	0.04	0.11	0.3	0.55	94	36.67	68.4
3.585176	0.03	0.02	0.33	0.62	98.2	60.8	48.5

Table C-31 Values of percent output of impurities for each Mean Pore diameter due to volume (five layers)

Dc_m v (mm)	V1	V2	V3	V4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
2.607051	0.34	0.05	0.42	0.19	39.4	23.6	4.8
2.670886	0.2	0.18	0.47	0.15	74.8	41.6	6.5
2.757407	0.16	0.31	0.25	0.28	70	27.5	18.2
3.16148	0.04	0.15	0.55	0.26	89.6	30.5	36.4
3.176426	0.09	0.15	0.3	0.46	81.6	18.8	22.6
3.28652	0.07	0.16	0.2	0.57	86.8	25.9	35.6
3.349192	0.05	0.09	0.38	0.48	90	41.8	38.5
3.378172	0.04	0.16	0.2	0.6	91	44	34.4
3.400091	0.04	0.11	0.3	0.55	91.6	33.3	45.3
3.585176	0.03	0.02	0.33	0.62	96.2	38.8	38.5

Table C-32 Values of percent output of impurities for each Mean Pore diameter due to volume (six layers)

Dc_m v (mm)	V1	V2	V3	V4	Percent output of impurities (Wt. %)		
					1.2-3.3 mm	4.2 mm	6 mm
2.607051	0.34	0.05	0.42	0.19	32.3	6.2	0
2.670886	0.2	0.18	0.47	0.15	54	11	2.4
2.757407	0.16	0.31	0.25	0.28	62	16.3	7.7
3.16148	0.04	0.15	0.55	0.26	81.2	30.1	34.4
3.176426	0.09	0.15	0.3	0.46	79.6	10	15.4
3.28652	0.07	0.16	0.2	0.57	77.8	22.1	18.2
3.349192	0.05	0.09	0.38	0.48	91.8	31.3	24.3
3.378172	0.04	0.16	0.2	0.6	88.4	31.5	20.2
3.400091	0.04	0.11	0.3	0.55	88.4	24.1	30.3
3.585176	0.03	0.02	0.33	0.62	95.6	29.8	24.3

الخلاصة

تستخدم الحشوات في عدة عمليات صناعية (امتصاص، امدصاص، تقطير، ترشيح). يتضمن هذا البحث دراسة خصائص الحشوة و اختبارها بطرق نظرية و عملية. الحشوة تكونت من اربعة انواع من الكرات الزجاجية ذات اقطار (١٠,٦-١٤,٩٧-٢٠,٨٩-٢٥,٨٤ملم)

الجانب النظري المعطى من قبل (latif) يتضمن ايجاد قطر الفتحة، معدل قطر الفتحة، الاحتمالية، و اوجدت النتائج باستخدام برامج الحاسوب (QBASIC, EXCEL) و اوجدت النتائج ان الاحتمالية تختلف لكل احتمالية.

الجانب العملي يتضمن عمل حشوة ذات تراكيب و طبقات مختلفة و لكن نفس الاقطار المستخدمة في الجانب النظري و وزن الشوائب قبل امرارها على الحشوة و بعد خروجها منها لايجاد النسبة المئوية للشوائب و قد استخدم ثلاثة انواع من الشوائب ذات اقطار(١,٢-٣,٣، ٤,٢،٦ملم).و قد اوجدت النتائج المحسوبة من الجانب العملي ان النسبة المئوية للشوائب تقل بزيادة عدد الطبقات و ايضا تقل بزيادة حجم الشوائب.

شكر و تقدير

اودُ أن أعبر عن خالص شكري وتقديري وَ امتناني العميق للمشرف الدكتور محمد نصيف لطيف لما بذله من جهد كبير و ارشادات سديدة و قيمة طوال فترة اعداد الرسالة.

أودُ أيضاً أن أشكر السيد رئيس القسم و موظفي قسم الهندسة الكيماوية لإبدائهم المساعدة اللازمة أثناء فترة البحث.

ولا أنسى أن أتقدم بالشكر و الامتنان إلى من لازمني طوال فترة البحث وخلال أصعب الظروف إلى أعز من في الوجود إلى أبي و أمي و جميع أفراد عائلتي فلهم جزيل الشكر و التقدير.

م..يسرى صابر كريم

ايجاد حجم الفتحة في حشوة مكونة من
اربعة حجوم من الكرات الزجاجية

رسالة

مقدمة الى كلية الهندسة في جامعة النهرين و هي جزء من متطلبات نيل

درجة ماجستير علوم في الهندسة الكيمياوية

من قبل

يسرى صابر كريم

(بكالوريوس في الهندسة الكيمياوية٢٠٠٢)

ربيع الاول ١٤٢٦

نيسان ٢٠٠٥