ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com
Journal DOI: 10.21474/IJAR01

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

A Study on Permeability analysis of 3-D Porous Models using Computational Fluid Dynamics (CFD).

V.Chaithanyavinay (M.Tech CAD), S.karuppudaiyan (Asst.Professor).
Dept. of Mechanical Engineering, SRM University, Tamil Nadu, India.

Manuscript Info

Manuscript History:

Received: 17 February 2016
Final Accepted: 18 March 2016
Published Online: April 2016

Key words:
3D Geometric models, porosity, CFD, permeability analysis, pressure drop, Darcy's law.

****Corresponding Author***

V.Chaithanya vinay.

Abstract

Permeability of scaffold is an important parameter which combines porosity, interconnectivity pore size and shape. It can influence on bone tissue engineering. The intrinsic permeability coefficient k of an open porous structure is ability to measure the fluid flow. Based on number of holes and standard pore diameter, 3D porous geometric models are created using commercial software SOLIDWORKS. In this study we found permeability co-efficient (k) of twelve different models with different shapes using Darcy's law by satisfying all assumptions. For these models porosity may vary in the range of 20% to 50%.To obtain permeability co-efficient(k), pressure drops are found using CFD analysis for twelve porous models by considering boundary conditions from previous literatures and comparing permeability co-efficient(k) of porous models.

Introduction:-

The bone scaffold should have a set of properties to provide mechanical support and simultaneously promote tissue regeneration. Among these properties, scaffold permeability is a determinant factor as it plays a major role in the ability for cells to penetrate the porous media and for nutrients to diffuse. This work is characterized the permeability of the scaffold microstructure, using computational methods. Computationally, permeability was estimated by homogenization methods applied to the problem of a fluid flow through a porous media.

The three dimensional (3D) scaffold pore architecture is a critical design variable, as it influences not only the mechanical properties but also the ability for cells to penetrate the scaffold and for nutrients, oxygen and waste products to diffuse through the scaffold. The difficulty in scaffold design has been choosing a design parameter (e.g. pore size and shape, porosity, interconnectivity, among others) that completely and accurately characterizes the effect of 3D scaffold pore architecture on mass transport and ultimately on bone growth.

The intrinsic permeability coefficient **k** of an open porous structure is a measure of the ability of a fluid medium to flow through it and, in the simplest formulation, it can be determine by measuring the amount of fluid (or gas) flowing through the porous material in a given time under an applied external pressure, as captured by Darcy's law.

$$K=Q\mu L/A\Delta P$$

where Q is the volumetric flow rate, ΔP is the pressure drop, A and L are the cross-sectional area and the length of the porous material, respectively, and μ is the dynamic viscosity of the fluid. It is assumed that Darcy's Law is valid if the Reynolds number (using the mean pores diameter) is below a limit somewhere between 1and 10. In order to assess the validity of Darcy's law, the Reynolds number (Re) was calculated as follows:

$$Re = (\rho \upsilon D)/\mu$$

ρ = density in kg/m^3

υ = velocity in m/s^2

D = diameter of pores in (m)

μ= dynamic viscosity in pa-s

Modeling:-

Models are created with porosity vary from 20 to 50 % approximately.3-D geometric models are made with specific dimensions which are taken from previous literatures. All designed porous geometric models has height H of 30 mm. For cylinder with diameter of 12 mm. For triangular prism of base is 12 mm. For square prism side of 12 mm. These models are designed in order to laterally confine the scaffold and to force the fluid to flow through its pores. Nine different geometric models were designed at same pore diameter (0.8mm) with varying number of holes in the model. Three models with hexagonal prism shape were created with pore diameter of 1 mm and for that three models with different number of holes. Totally twelve models are created by using SOLIDWORKS and converts into .IGES format and then imports to ANSYS(FLUENT) for determining the permeability co-efficient **k** by using Darcy's law.

Figure 1: cylinder

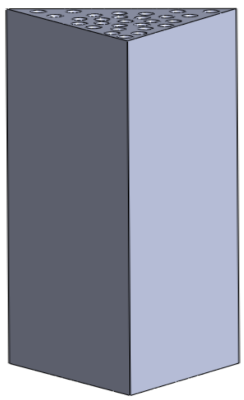


Figure 2: triangular prism

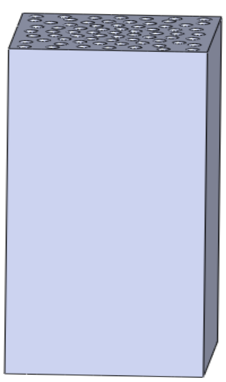


Figure 3: square prism

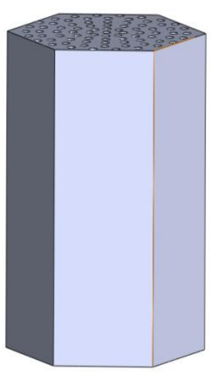


Figure 4:hexagonal prism

Porosity Determination:-

Porosity can be calculated by using formula for 3-D porosity. By varying number of holes different porosities can be achieved.

For 3D porosity:
Porosity = (volume of pores/Total volume of object)

Porosities for twelve different models are calculated and tabulated as follows:

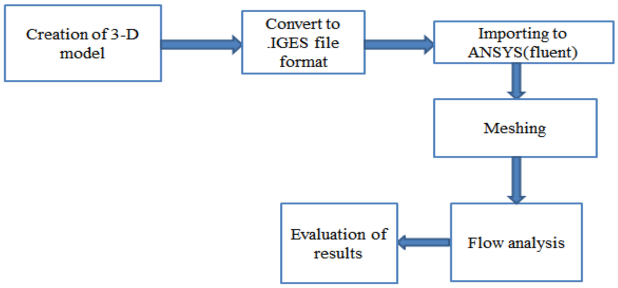
S.No.	Number of holes	Hole diameter(in mm)	Porosity(in %)
Cylindrical prism			
1	59	0.8	26.2
2	78	0.8	34.6
3	96	0.8	42
Triangular prism			
1	28	0.8	23.1
2	35	0.8	29.7
3	43	0.8	35.5
Square prism			
1	70	0.8	24.44
2	84	0.8	29.3
3	93	0.8	33.5
Hexagonal prism			
1	99	1	20.7
2	123	1	25.82
3	151	1	31.6

Seven porous models has same pore diameter of 0.8 mm ,for two porous models has diameter of 1mm and there is a variation in number of holes and calculating porosities of 3-D models to study the permeability analysis.

Permeability Analysis:-
The permeability k for the nine geometric models scaffold porosities was quantified using computational (CFD modeling) method. In all cases the value of k was calculated using Darcy's law and finding pressure drop across the scaffold. To validate the Darcy's law Reynolds's number in the range between 1 to 10.

$$Re = \rho v D_{pores}/\upsilon$$

To determine permeability co-efficient (**k**) pressure drop should be determine. Ansys (FLUENT) solver is using in this study to obtain pressure drop across the model.

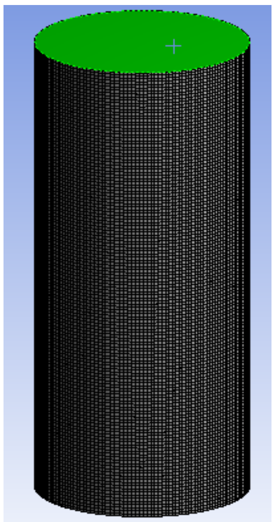


Flowchart: Methodology for finding Pressure drop in CFD

Fluid Flow Modeling:-
Twelve different 3D geometrical models per geometrical porosity were built and meshed in ANSYS(FLUENT) using automatic method. The difference between the models is the way in which numbers of holes were quantified and calculating porosities of 3D geometric models. To predict the pressure and velocity fields inside the scaffolds, the commercially available finite volume code ANSYS(Fluent) was used to set up and solve the fluid dynamic problem.

The culture medium was regarded as an incompressible and homogenous Newtonian fluid with the properties of water (a viscosity of 10^3 Pa s and a density of 10^3 kg/ m^3). The method used in solution set up is pressure based method and
Absolute velocity formulation. Boundary conditions at inlet velocity is not exceeding 5 mm/s at atmospheric pressure.

inlet



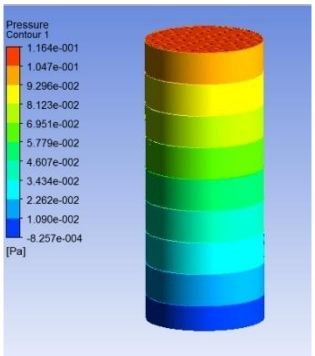
Fluid Flow Model

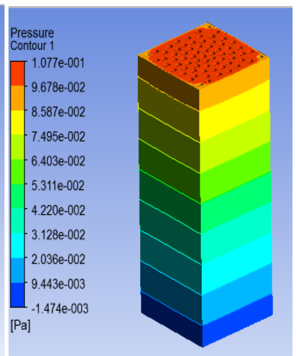
A zero gauge pressure was applied to the outlet, symmetry conditions to the lateral surfaces and no-slip conditions to the walls of the scaffold. Steady-state, Navier-Stokes equations were used to describe the flow problem. The pressure drop was obtained for all the models and used to calculate the permeability coefficient.

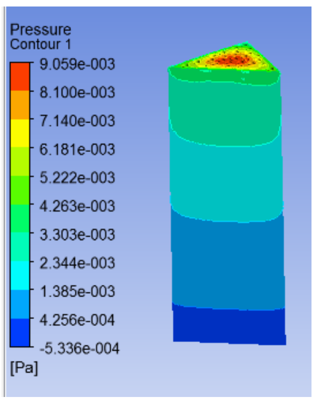
Results and Discussion:-

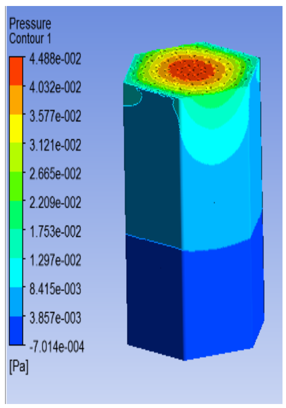
For twelve different models the velocity and pressure distribution were analyzed. The pressure at the inlet was calculated as the mean value of the pressure distribution in a cross section perpendicular to flow direction corresponding to the inlet.

The pressure value at the outlet was equal to zero for all the models, according to the assigned boundary condition. The resulting value of the pressure drop across the 3D geometric models and the assigned velocity at the inlet were used to calculate the permeability coefficient.









As shown above pressure drops across 12 different models are determined.

Permeability co-efficient can be determined by using Darcy's law and there is an increase in pressure drop as porosities of the 3D models increases. Then permeability co-efficient(K) decreases, because according to Darcy's law, permeability co-efficient is inversely proportional to pressure drop:

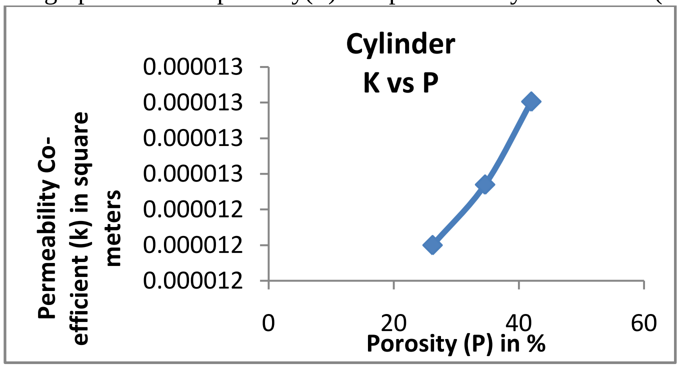
$$\mathbf{K} \quad \alpha \quad 1/(\mathbf{\Delta p})$$

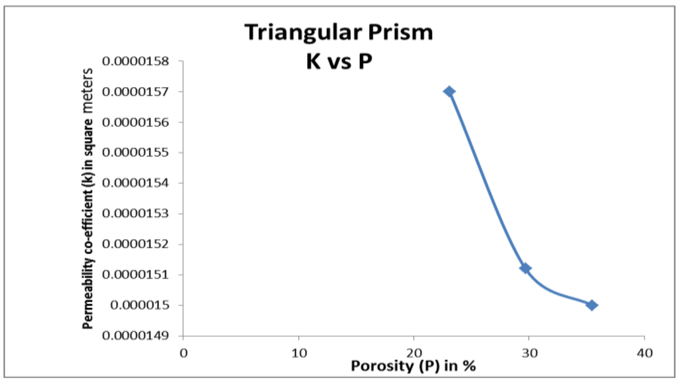
Permeability co-efficient(k) of different models are tabulated as follows:

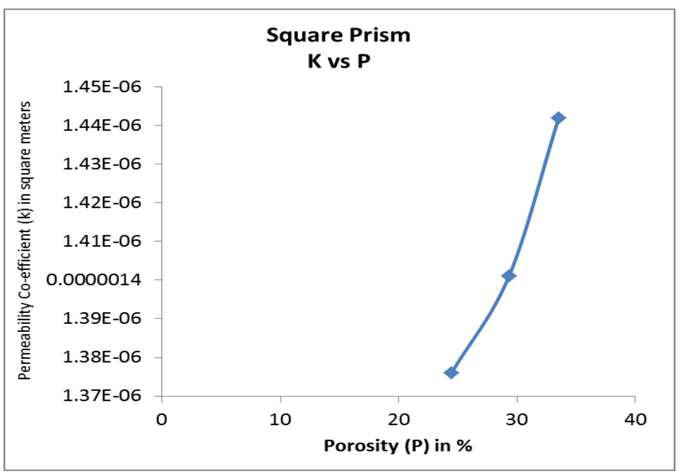
S.No.	Porosity(in %)	Permeability co-efficient(k in m2)
Cylindrical prism		
1	26.2	0.0000126
2	34.6	0.00001294
3	42	0.000013406
Triangular prism		
1	23.1	0.0000157
2	29.7	0.00001512
3	35.5	0.000015
Square prism		
1	24.44	0.000001376
2	29.3	0.000001401
3	33.5	0.000001442
Hexagonal prism		
1	20.7	0.00000329
2	25.2	0.000003293
3	31.6	0.00000328

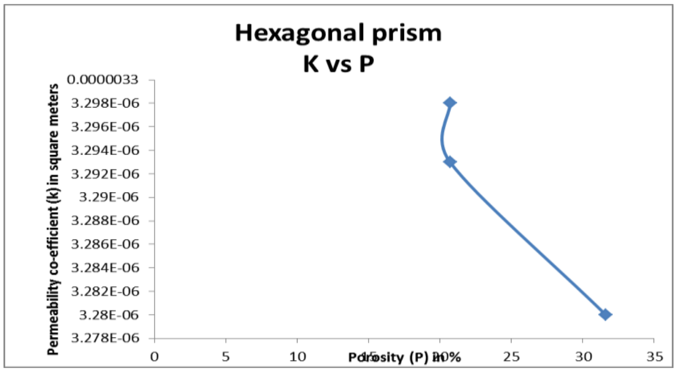
Graphs:-

Inlet boundary conditions were taken from previous literatures for fluid flow modeling and the results were recorded the graphs between porosity(P) and permeability co-efficient(K) for different shapes are shown below:









As shown in above graphs, curves are varying based on porosities and permeability co-efficient(k) of models with different shapes. CFD models are built based on previous literatures and studied variation of pressure drops using Darcy's law and permeability co-efficient(K) of twelve different models were found that there is a mixed results for cylinder and square prism there is an increase in permeability co-efficient(k) by increasing porosity. For triangular and hexagonal prism there is an decrease in permeability co-efficient with increase in porosity. According to Darcy's law permeability co-efficient is inversely proportional to pressure drop.

Conclusion:-

There is a variation of permeability co-efficient by varying shape of 3D geometric porous models. It is clear that there is also a variation of k by varying porosity.so, from this work it is evident that, the value of k depends on shape, size and porosity of 3D porous models and from Darcy's law k is inversely proportional to pressure drops across the models. pressure drops across the models are found from this method. The method developed can be extended to other different 3D geometric models.

References:-

[1] S. Truscello, G. Kerckhofs, S. Van Bael, G. Pyka, J. Schrooten, H. Van Oosterwyck, Prediction of permeability of regular scaffolds for skeletal tissue engineering: A combined computational and experimental study, Acta Biomaterialia 8 (2012) 1648–1658

[2] Luis Cardoso, Susannah P.Fritton, Gaffar Gailani, Mohammed Benalla, Stephen C. Cowin Advances in assessment of bone porosity, permeability and interstitial fluid flow, Journal of Biomechanics 46 (2013) 253–265

[3] Ardiyansyah Syahrom, Mohammed Rafiq Abdul Kadir, Jaafar Abdullah, Andreas Öchsner, Permeability studies of artificial and natural cancellous bone structures, Medical Engineering & Physics 35 (2013) 792– 799

[4] M.R. Dias, P.R.Fernandes , J.M.Guedes , S.J.Hollister, Permeability analysis of scaffolds for bone tissue engineering, Journal of Biomechanics 45 (2012) 938–944

[5] P.G.Coelho , P.R.Fernandes , H.C.Rodrigues , J.B.Cardoso, J.M.Guedes
Numerical modeling of bone tissue adaptation - A hierarchical approach for bone apparent density and trabecular structure, Journal of Biomechanics 42 (2009) 830–837

[6] Pedro Goncalves Coelho, PauloRuiFernandes , HelderCarrico Rodrigues
Multiscale modeling of bone tissue with surface and permeability control, Journal of Biomechanics 44 (2011) 321–329

[7] Teja S. karande , Joo L. ong and C. Mauli Agrawal, Diffusion in Musculoskeletal Tissue Engineering Scaffolds: Design Issues Related to Porosity, Permeability, Architecture, and Nutrient Mixing, *Annals of Biomedical Engineering*, Vol. 32, No. 12, December 2004 (©2004) pp. 1728–1743