INVESTIGATION OF FLUID FLOW THROUGH CELLULAR STRUCTURES

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To my lovely husband, thank you for your patience and understanding.
To my family who has always given me support to pursue my dreams.

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In the name of Allah, Most Gracious, Most Merciful.

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ABSTRACT

In this study, the cellular structures models of a porous medium containing a fluid flow phase within the pores or spaces of the solid matrix are investigated. A computational fluid dynamics of the three dimensional (3D) macro structures is developed from simple to complex model. Nine model variants are designed with different structure and geometry. To this end, the influence of cellular structure on the fluid flow, in terms of velocity, wall shear stress and pressure drop are investigated using the commercial FLUENT software. The acquired permeability values from obtained pressure drop and Darcy's law are compared with permeability values calculated from Kazeny-Carman equation, there is a good agreement for permeability values for these two types of values which can validate the simulation.

ABSTRAK

Dalam kajian ini, struktur sel sebuah model medium berliang, yang mengandungi fasa aliran bendalir dalam pori-pori atau ruagan matriks padu disiasat. Simulasi dinamik bendalir tiga dimensi struktur makro dibentuk dari sebuah model yang mudah, kepada sebuah model yang kompleks. Sembilan model dibentuk bengan struktur dan geometri yang berbeza. Pengaruh struktur sel pada aliran bendalir, dari sudut halaju, tekanan dinding ricih, dan susutan tekanan dikaji menggunakan perisian FLUENT. Didapati nilai ketelapan yang diperolehi dari susutan tekanan dan hukum Darcy, dibandingkan dengan, nialai ketelapan yang dikira dari persamaan Kazeny-Carman, mempunyai perkaitan. Nilai-nilai ketelapan ini boleh mengesahkan simulasi yang teloh dijalankan.

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LIST OF SYMBOLS

q	-	Flow rate
k	-	Permeability
A	-	Cross-section area
μ	-	Viscosity
$\frac{dP}{dL}$	-	Pressure gradient
D_H	-	Hydraulic diameter
V/S	-	The ratio of volume-to-surface of the pores
Re_K	-	Reynolds number
v	-	Velocity
ρ	-	Density of fluid
Q	-	Flux of fluid
v_p	-	Pore velociy
v_D	-	Darcy velocity
ε	-	Porosity
μ	-	Dynamic viscosity
C	-	Drag term
Δp	-	Pressure-drop
L	-	Length
x_i	-	Various fluid flow velocities
y_i	-	Various pressure-drop per unit length values
v_x	-	Volume flow rates per unit cross-section area in the x direction
v_y	-	Volume flow rates per unit cross-section area in the y direction

v_z	-	Volume flow rates per unit cross-section area in the z direction
F_i	-	Dimensionless inertia term coefficient
$\langle P \rangle^f$	-	Average pressure inside the fluid
J	-	Unit vector oriented along the velocity vector
ϕ	-	Conserved quantity
Φs	-	Sphericity of the particles in the packed bed
Dp	-	Diameter of the related spherical particle

LIST OF ABBREVIATIONS

CFD	-	Computational Fluid Dynamics
GUI	-	Graphical User Interface
CAD	-	Computer-Aided Design

CHAPTER 1

PROJECT OVERVIEW

1.1 Background of the Problem

Fluid flow in a porous medium is a common phenomenon in nature, and in many fields of science and engineering. Important flow phenomena include transport of water in living plants and trees, and fertilizers or wastes in soil. Moreover, there is a wide variety of technical processes which involve fluid dynamics in various branches of process industry. Fluid flow through a porous medium is essentially a two-phase problem that is composed of the flow of a fluid-phase and a solid matrix particle phase. However, for a matrix in which the pores are stationary, the solid matrix is assumed to be rigid and hence, it is usually assumed as a single-phase fluid. In many cases the porous structure of the medium and the related fluid flow are very complex, and detailed studies of these flows pose demanding tasks even in the case of stationary single-fluid flow.

Fluid flow through a porous medium is applied in technological, environmental, and medical applications. A material must pass one of the following two tests in order to the qualified as a porous medium. It must either contain spaces filled with a fluid or be permeable to a diversity of fluids. A porous material has a specific permeability, which is uniquely determined by the pore geometry and which is independent of the properties of the penetrating fluid. Practically all macroscopic properties of a porous media are influenced by the pore structure. Another important macroscopic parameter of the porous structure is the porosity that represents the empty space available for a fluid to pass. 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 the permeability. 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 yet been developed. On the other hand, due to the complexity of the geometry in porous media, accurate analytical solutions are difficult to obtain and it can be done with very few exceptions (Kaviany, 1995).

The concept of porous media is used in many areas of applied science and engineering: mechanics (acoustics, geomechanics, soil mechanics, rock mechanics), engineering (petroleum engineering, construction engineering), geosciences (hydrogeology, petroleum geology, geophysics), biology, biophysics, material science etc. Transport of fluid, mass, and heat through porous media is a subject of interest that has emerged to be known as a separate field of research. The porous media has played a critical role in wide range of fields of science such as biomedical engineering and tissue engineering, biological membranes and bioreactors. The study of blood flow and perfusion bioreactor through the porous scaffold and other organs are the most advanced applications of porous media in biomedical engineering.

1.2 Statement of the Problem

The fluid flows through an inlet with a uniform velocity, passes through a cubic cellular structure and exits through the outlet. The rectangular channel with the modeled cubic cellular structure is shown in Figure 1.1.

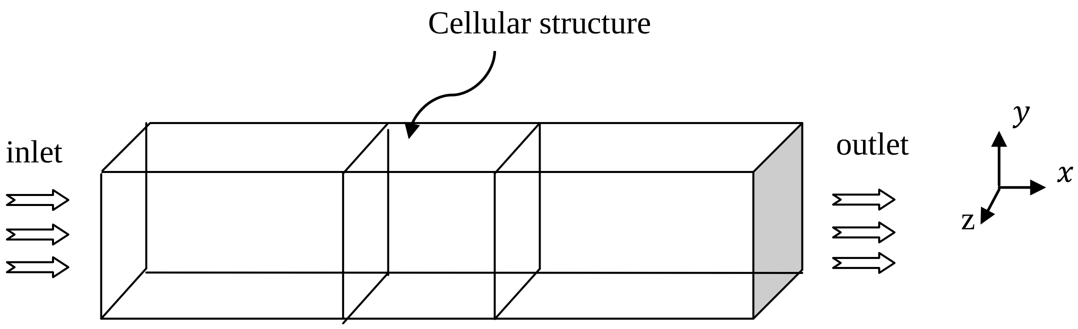
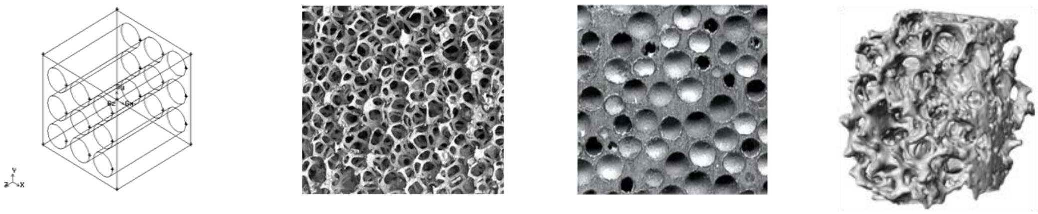


Figure 1.1 Rectangular channel within cellular structure geometry for flow modeling.

Many attempts have been carried out in order to simulate the fluid flow through a cellular structure such as simplified model structures, porous hollow sphere structures, open cell metal foam and human bones, respectively, are shown in Figure 1.2. This study investigates the characteristics of a fluid (liquid or gas) flow through a rigid, cellular structure. The use of a cellular structure in fluid-flow applications requires entire understanding of the behavior of the fluid flowing through the porous structure, in which the pressure gradient, velocity distribution through the cellular structure and shear stress are significantly required. Hence, in this present work the “Computational Fluid Dynamic” (CFD) analysis is used to model the flow through a cellular structure; to this end, modeling a flow in a rectangular channel, the pressure drop and the uniformity of the flow through a cellular structure can be determined using this method. The main purpose of this study is to apply the finite volume method for solving problems involving a fluid flow through cellular structures by means of the FLUENT software. FLUENT is used to model the flow of the fluid through cellular structure geometry which enables to analyze the flow field properties.



(a) (b) (c) (d)

Figure 1.2 (a) cubic arrays of pore circular cylinders, (b) Open-cell aluminum foam, (c) Cross section of metallic hollow sphere structures (Fiedler T, 2007), (d) Computed tomography scan of human bones (www.aurorahealthcare.org).

1.3 Objectives of the Project

The objectives of this study can be summarized as follows:

1) To demonstrate the use of a commercial available computational fluid dynamics code, FLUENT, in simulating flow through cellular structures.

2) To examine the effects of the cellular structure geometry on the fluid flow. Effects such as pressure drop etc. will be analyzed as a function of the cellular material characteristics.

1.4 Scopes of the Project

1) Generate and meshing the geometry of the cellular structure from a simple to a complex geometry.

2) To investigate the fluid flow behavior for different cellular structures with different porosity by using the FLUENT software.

3) Validation of obtained result by comparing with earlier research.