PARAMETRIC STUDIES OF CAPILLARY FLOW FRONT VELOCITY

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Dedicated to my family for their endless support and encouragement

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ABSTRACT

Currently, active research on capillarity are being conducted in various fields such as biomedical, thermodynamic, electronic, hydrology, geology and aerospace. The study mainly focuses on the flow front velocity (V_{ff}) for non ideal-case of capillary, spceifically to assist the designer of a system or process involved in fluid dynamic flow. Observation is conducted at difference inclination angle alpha (α) for both ascending and descending capillary flow. The real time computer screen displayed of 100× magnified 2D microscopy video of fluid flow front is analyzed to produce scattered exprimental data of the flow front velocity (V_{ff}) against travelled distance (z). The sufficient curve fitting result has been produced which the equation has negative power ($-b$) with an algebraic expressions of $V_{ff} = a\ z^{-b}$. It has been transformed into $V_{ff} = f(t)$ for the data of flow front velocity against time (t) for capillary flow related parameters investigation such as viscosity, diffusion, specific capillary geometry, inclination angle, deceleration, force due to the mass of retaining fluid and fingering flow type in the capillary fiber. The result of mathematical analysis such as an evaluation of variable values form curve equation, derivative and solving of parametric equations is used to establish the references to any process or system design for a micro machine.

ABSTRAK

Ketika ini penyelidikan berkenaan kekapilarian giat dijalankan dalam pelbagai bidang seperti bioperubatan, termodinamik, elektronik, hidrologi, geologi dan aeroangkasa. Fokus utama kajian ini adalah tentang halaju hadapan aliran, (V_{ff}) bagi kes tak sempurna bagi kapilari, bagi membantu pereka bentuk sistem atau proses yang dikaitkan dengan aliran dinamik bendalir. Pemerhatian dibuat bagi pelbagai sudut kecondongan, alpha (α) untuk aliran kekapilarian menaik atau menurun. Paparan mikroskop 2D aliran hadapan bendalir semasa pada skrin komputer dengan pembesaran 100× dianalisis untuk menghasilkan taburan data graf halaju hadapan aliran, (V_{ff}) melawan jarak yang dilalui *(z)*. Suai lengkung yang baik beserta rumus berkuasa negatif ($-b$) berungkapan algebra $V_{ff} = a\, z^{-b}$ dapat dihasilkan. Seterusnya rumus ini dijelmakan kepada $V_{ff} = f(t)$ bagi data halaju hadapan aliran melawan masa (t) untuk menganalisa beberapa parameter yang berkaitan aliran kekapilarian seperti kelikatan, peresapan, geometri tentu kapilari, sudut kecondongan, lambatan, daya bagi jisim bendalir terserap serta pembentukan aliran jejarian dalam serat kekapilarian. Keputusan daripada analisis matematik iaitu nilai pemboleh ubah dari persamaan lengkung, kebedaan dan penyelesaian persamaan parameter diguna sebagai rujukan kepada sebarang reka bentuk proses atau sistem bagi suatu mesin mikro.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Capillarity has been studied in various fields such as biomedical, thermodynamic, electronic, hydrology, geology and aerospace. The capillary action in those studies do not exclusively defined any clear parametric relationship to assist any design of a system or processes. Normally testing was done to reconfirm any variation or homologous regression to a specific area of interest. It is thought that, there is a real need to define as much as possible the significant parameter despite the known basic equation from fluid dynamic potential energy calculation.

1.2 Background of Research

The capillary action that has been studied specifically in the porous media is important in many scientific fields including hydrology, petroleum reservoir engineering, biomedical, thermodynamics, electronic, geology, aerospace, and soil science.

There are many questions to be asked by a designer when considering capillarity affected system or processes.

As a designer, question like gravitational correlation of non-ideal case of capillary flow front is not represented in tangible graph. What happens if the fluid moving in micro channel with variation of gravitational along the fiber bundle column which is no factor present to be referred rather than basic rheological test of surface tension.

$$Gravitational\ force = h\pi r_c^2 \rho g \tag{1}$$

$$Surface\ tensional\ force = 2\pi r_c\, \gamma \cos\theta \tag{2}$$

Where h is fluid height, r_c is tube radius, ρ is fluid density, g is gravity, γ fluid surface tension, and θ is contact angle. By equating these two basic equations (1) and (2), one could calculate the capillary rise quite accurate. Even though the formulation satisfies the basic principle, where does the equation coincide in the subject like flow pressure variation when radial inconsistency exist. These formulae have become too basic for consideration in a real design application where another set of complicated equations are deployed into action and finally required experimental result for correction factor. In theories Young's and Darcy happened to contribute a significant finding for solving many capillary flow problems in term of mathematical approach. However this mathematical approach is not easily understood for common design application due to the complication of the established mathematical model.

In another interest of wetting and drainage phenomenon a viscous liquid contain micro bubble has been reported flowing through a capillary filter by gravity separating the micro bubble behind. This discovery has solved air bubble diffusion problem in composite laminates.

During design of a process or system concerning capillary motion the flow front speed is very important when it come to the critical aspect of time, production, effectiveness and homogeneity.

The studies of flow front which in conjunction to capillarity will bring more understanding towards other parameters which can be taken as non-dimensional subject according to specific conditions improve by relative factor will certainly assisting design decision making and selection of material.

1.3 Problem Statement

Fundamental study for physical elements such as inclination angle, distance, flow resistance and gravitational relationship to capillary flow process with time dependent in early design process need to be identified to avoid inaccuracy and reduce error of material selection and geometry.

1.4 Objective

The objective of the study is as follows:

1. Evaluate the related parametric because of the need in micro design.
2. To produce tangible product in term of graph, equation from graph and table for the non-ideal case

1.5 Scope of Study

The scope of the study is as follows:

1. Fiber and substrate capillaries physical characteristic identification for experimentations.

2. Flow Front monitoring in test rig control system with appropriate visual observation.

3. Studies on existing experimental technique by previous research.

4. Mathematical analysis and data processing studies.

5. The study has entirely using of fiberglass bundle capillary column with pigment colored of distilled water for experimentation.

1.6 Research Methodology

In capillarity, capability of the fluid to penetrate the pore in capillary medium within specific time known as a speed of fluid front or fluid flow velocity, (V_{ff}). In this experiment, that quantity is measured in millimeter per second$\left(\frac{mm}{s}\right)$. In this study, the capillary medium used was 100 mm glass fiber (fiberglass) bundle column consist of uniform filament diameter of 10μm.

Fiberglass bundle capillary column with pigment colored of distilled water (pH value is 7) for experimentation. Colored water is used for better contrast under the visual or video observation. The distance of fluid travel observation is limited up to 100mm as the capillarity speed reached almost asymptotic.

The limitation of the video specification effect the visual quality as the limitation of the speed is 30 frames per second only. This makes the speed higher than that limitation become impossible to be produced. Consequently, the beginning fluid speed with the very high velocity was undefined.

If possible, the experiment results need to be verified by make comparison of its related parametric with any equation which has established by previous research and study. Gravitational influencing flow front speed gradually up to its maximum

forces against flow as inclination plane set with its alpha angle, α between horizontal as zero degree to vertical of 90°.

Proper experimental plan is necessary to achieve good results in conducting research with data acquire from series of experiments. Below is the detail of the method use in conducting the research which depends on experiments result basis.

Description of Methodology:

a. Literature review - studies on current and previous research work for the purpose of cross referencing and data verification.

b. Test rig design, fabrication and setup, equipment calibration, speed setting and fiber substrates sample preparation.

c. Experimental work and testing on fiber substrates and wetting fluid intervention by parametric variation effect of surface profile, surface tension, dimensional properties, porosity and pore-size on the flow front criteria and velocity profile. Using appropriate micro imaging and microscopy equipment mounted on a parallel moving platform, a real time images profile can be captured continuously for analysis.

d. Experimental analysis - Progressive video image can be analyzed using image analyzer technique to measure the flow front advancement velocity to establish the parametric relationships.

1.7 Research Expectancy

1. Expected of new findings, knowledge in which the correlation in micro level fluid system and process design will be established.

2. Specific or potential applications are required for fluid mechanics system, composite material processing and textile product toward

current technology which demand for smart material and design technique.

1.8 Significance of Study

Knowledge of capillarity is important in oil and gas energy recovery, soil and groundwater hydrology, dyeing of textile fabrics, ink printing, and a variety of other fields. Summarizing of its applications according to technology development as follows, regardless type of fluid and material used.

1. Analysis of permeability in fiber filling process in fiber composite material for better quality and reducing cost.
2. Liquid chromatography, separations process, colloid sample collection, water pollution and water treatment.
3. Hydrodynamic analysis, slope and surface water drainage system.
4. Membrane material and fabrication technology
5. Micro transport in biology system.
6. Capillary tube metering device such as a capillary tube is a refrigerant control which is common types in air conditioner expansion valve.

In addition, there are wide areas of its applications in biomedical engineering as it has only recently emerged as its own discipline. It interdisciplinary field has influenced and overlapping with various other engineering and medical fields and provide high prospective in capillary study

1.9 Research Methodology Flowchart

Figure 1.1 shows the research methodology flowchart of capillary flow front velocity (V_{ff}) study which the expecting of producing the tangible graph and capillarity related parametric analysis result for the designer. The flowchart summarized the research methodology to be applied in this study.

The smooth curve fitting however depend on the data collected from the experiments. A mathematical approach should be used to evaluate experiment data for model identification which simultaneously checking the error occurred in the system.

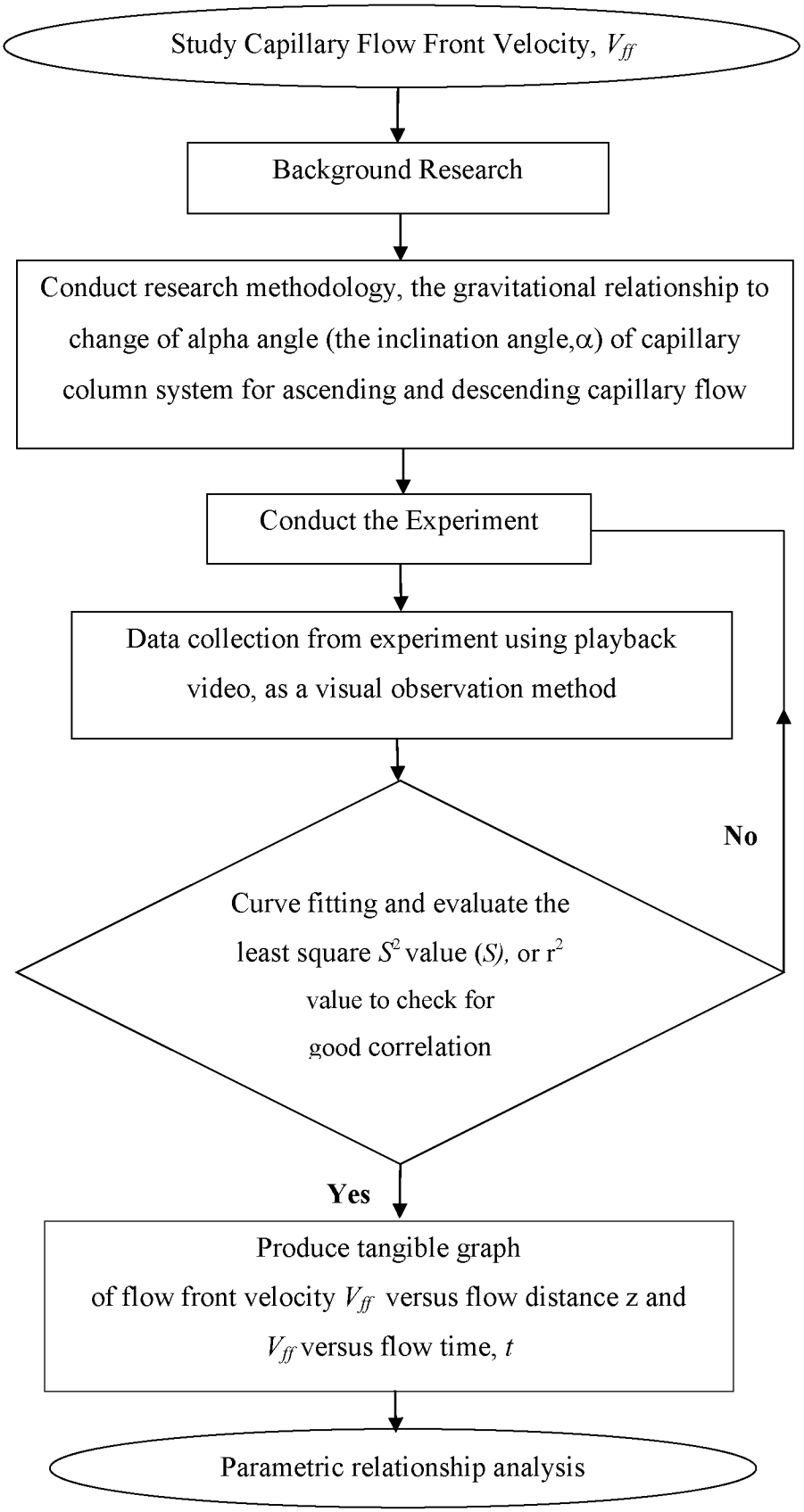

Figure 1.1: Research methodology flowchart

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