STUDY ON BEHAVIOR OF PARTICLE FLOW IN THE LID DRIVEN CAVITY BASED ON VARIOUS GEOMETRIES

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ABSTRACT

This study is focusing on the behavior of particle flow in the lid driven cavity based on various geometries. The study is about to determine the fluid flow behavior in equilateral triangle and semi ellipse lid driven cavity shape. The silk particle is uses in the experiments are slightly buoyant towards water. Validation of flow was done by comparing the flow with past researchers. The fluid flow speed is ranging from Reynolds number of 1612, 2687 dan 5610 with various particle quantities. The flow is based on horizontal translating motion where the initial conditions of the particle remains at rest at the bottom wall of the lid driven cavity. The results shows for equilateral triangle shows that the silk particle behavior move to the preferential path and for semi ellipse lid driven cavities the silk particle behavior rotates in a swirling motion at the center of the lid driven cavity due to Taylor Gortler like vortices formations. The problem and recommendations for improvements are also being discuss in this thesis.

ABSTRACT

Kajian ini memberi tumpuan kepada tingkahlaku terhadap aliran partikel di dalam rerongga berdasarkan pelbagai bentuk. Kajian ini adalah untuk mengenalpasti tingkahlaku aliran partikel di dalam bentuk segi tiga sama sisi dan elips separuh. Partikel sutera digunakan di dalam ujikaji adalah sedikit terapung terhadap air. Pengesahan aliran dibuat dengan membuat perbandingan aliran yang dibuat oleh penyelidik terdahulu. Halalaju aliran cecair adalah antara nombor Reynolds 1612, 2687 dan 5610 dengan pelbagai kuantiti partikel sutera. Aliran adalah berdasarkan pergerakan aliran mendatar di mana keadaan partikel tidak bergerak di dasar di dinding rerongga. Keputusan yang diperoleh oleh segi tiga sama sisi menunjukkan tingkahlaku partikel sutera bergerak seperti yang diinginkan dan untuk elips separuh tingkahlaku partikel sutera berpusing secara mendatar di tengah-tengah bahagian rerongga oleh kerana pembentukan vortex seakan Taylor-Gortler. Masalah dan cadangan untuk penambahbaikan juga dibincangkan di dalam thesis ini.

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f	Images frames
s	Seconds
Re	Reynolds Number
ρ	Density
L	Length of conveyer
μ	Dynamic Viscosity

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Research in lid driven geometry has been study for the purpose numerical and experimental study which can validate the flow topologies and vortices formations. The study on numerical code for lid driven cavity flow started as early of 1892 when U.Ghia et al (1982) solve the numerical code for viscous incompressible square lid driven cavity flow with length to wide ratio is 2:1. Experimentation on lid driven cavity were conducted prior to U. Ghia et al at (1982) by J.R Koseff and R.L.Streets (1984) by using particle streak and dye emission technique which flow observation in lid driven cavity for length to wide ratio of 3:1 for rectangular lid driven cavity which later improved to particle tracking system or particle imaging system or both.

Researchers have been interested in the experimental regions which the purpose of the experiments is to validate the codes for lid driven cavities. The improvement in technology such as in software and hardware were able to calculate the flow in experimental and numerical area which able to simulate and calculate complex and discrete equations such as mapping the fluid flow topologies in computational domains. Other than numerical simulations method, there are many others methods of mapping flow visualization and flow characteristics such as finite volume method (T.P.Chiang et al, 1998), direct numerical solutions (Ercan Ertuk, 2009),(Hatice Mercan and Kunt Atalik, 2007), (M.S.Idris and N.M.N.M.Ammar, 2010) and Navier-Stokes equations (U. Ghia et al,1892), (Ercan Ertuk and Orhan Gokcol,2007), (Salvador Garcia,2011).

1.2 PROJECT BACKGROUND

Analysis of lid driven cavity have been conducted to understand the flow topologies such as velocities profile, boundary layer formations, streamline patterns, vorticity contours, flow stabilities and effect of the Reynolds number on the flow structure. Numerical simulations were conducted on the lid driven cavity flow that have been studied for a long time because of their broad range of applications such as in natural, industrial and biomechanical regions (C. Migeon et al. 2000). Computational fluid have made possible to make the simulations of fluid flow analysis by integrating it into software to generate simulations such as FLUENT® code (M.S Idris and N.M.N.M Ammar, 2010).

1.3 PROBLEM STATEMENTS

The basic flow visualizations are view for perturbations eddy formations in 2D flows. The formations of eddies in fluid flow are divided into two parts which is the primary and secondary eddies. Numerical experiments such as in computational equations, especially in solving Navier-Stokes equations were domain for square lid driven cavity were done as early as 1892 by U. Ghia et al (1892), while the square and rectangular fluid flow have been discussed in experimental region by J.R.Koseff and R.L.Streets (1894), C.Migeon et al (2002) and by Alex Liberzone (2011).

The secondary eddies, the so-termed corner vortices, located close to the cavity span end-walls, take a large part in span wise fluid transport (T.P Chiang et al. 1998). The primary eddies is at the center of the lid driven cavity driven by large vortices as seen in **Figure 1.1**.

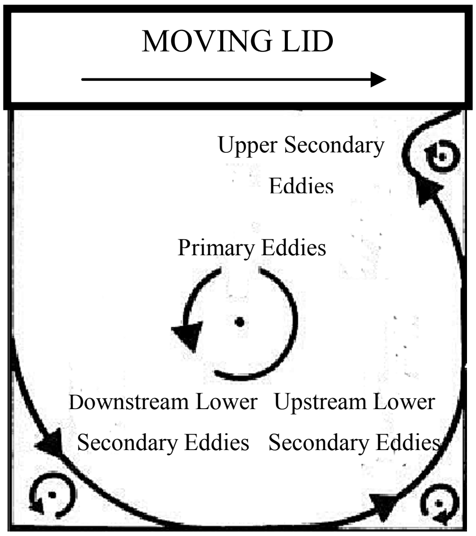

Figure 1.1: Sketch of 2D fully develop cross sectional flow in lid driven square cavity.

Source: C. Migeon et al (2000)

Researchers are interested in the development of 3D flows due to fully view the developments of the flow itself therefore experiments were conducted. The most simplest form of flow studies were done basely in a parallepedic lid driven cavitities experimental regions which have been done as early as 1894 by J.R.Koseff and R.L.Street (1894). Other experimentations were done in order to analyses the lid driven cavity effect on the flow establishment phase such as experiments conducted by C.Migeon et al (2002) and followed by the start-up flows analysis which focus on the Taylor-Gortler-like vortices which can be seen only in 3D flows which focuses on the unsteady flow characteristics to become steady by C.Migeon(2000).

Although validation of numerical flow in parallepedic lid driven cavity flow were experimented, there should be also validation of flow in different geometries such as equilateral triangle and semi-ellipse lid driven cavity flow. The flow establishment in different geometries were conducted in understanding the cavity flow especially the connection of vortex, stream function contour and streamlines (M.S.Idris and N.M.N.M Ammar. 2010) which contain variety of flow pattern such from 2-D to 3-D, secondary, corner and stream wise eddies, chaotic trajectories and more which can be obtain in experiments (Alex Liberzon ,2011).

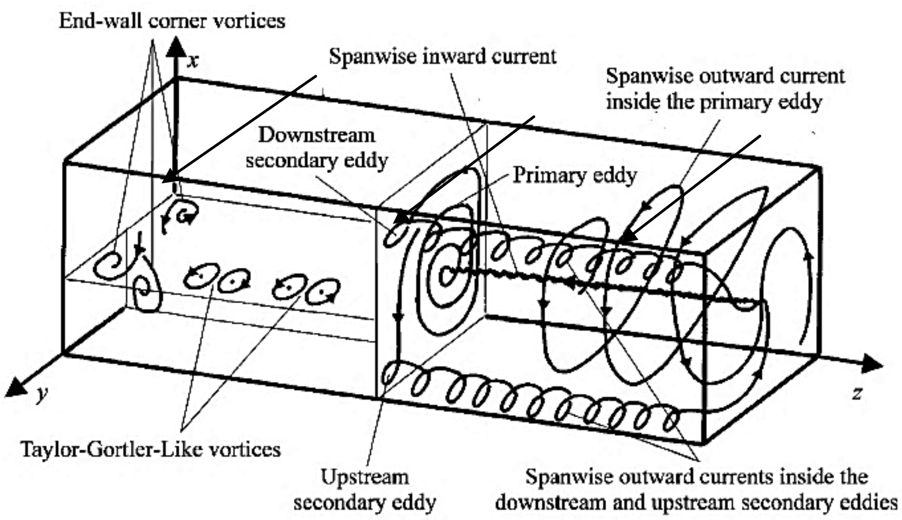

Figure 1.2: Sketch of 2D fully develop cross sectional flow in lid driven square cavity.

Source: C. Migeon et al (2002)

1.4 OBJECTIVES

There are two main objectives which the study involves which are particularly based on equilateral triangular shape lid driven cavity and semi ellipse lid driven cavity.

The objectives of the study are;

1. Design and experiment the lid driven cavity flow
2. Analyze the lid driven cavity flow for fluid flow behavior in lid driven cavity particularly on semi ellipse and isosceles triangular cavity.
3. Validations of flow based on benchmark results.

1.5 SCOPE OF STUDY

The main scopes of this study is about the limitations and boundary conditions set for the experiments itself such as particular attentions of the study, the control parameter for Reynolds numbers, silk positioning, silk ratio, medium of flow the geometric shapes of lid driven cavity.

The scopes of the project are limited to:-

1. Particular attention of validation of flow
    a. The formation of primary/secondary eddies.
    b. 2D and 3D particle flow

2. Control of parameter
    a. Various Reynolds numbers
    b. Positions of the silk particle allowed to suspended in early positions (S.J. Tsorng,2007)
    c. Manipulations of silk particle.(50 cm length and number of thread is 5,6 and 7)
    d. Water as a medium flow.

3. Lid driven cavity geometric shape
    a. Equilateral triangle shape with length to wide ratio of 1:1
    b. Semi ellipses-circle shape with length to wide ratio of 1:1

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Researchers through qualitative measurements or quantitative measurements or both have conducted particle flow analysis in lid driven cavity. In order to understand what the particle flows behaviors inside cavities looks like, the basic flow structure for equilateral triangle and semi ellipse lid driven geometric shape were used as a benchmark for validation of flow topologies.

Flow topologies are the key to validate a flow structures that analytical results can be validate or be research by using qualitative measurements and quantitative measurements, which later comparison can to the benchmark data. The important of topological flow measurements are to analytically give methods to measures the flow streamlines, streaklines and pathlines and texture advections which were to find the main critical points in topologies tracking

Particle flow validation were done through the same analysis but the main critical point attention at the particle behavior, particle suspension, particle rotations and particle translation motions inside the lid driven cavities during flow movements.

2.2 TYPE OF FLOW MOVEMENTS.

This experimental analysis were done primilarly based on translating lid driven cavity flow (J.R. Koseff and R. L. Street, 1984),(H.S. Rhee et al, 1984),(S.J. Tsrong et al, 2005 and 2007) and (Alex Liberzone, 2011). There is also oscillating type lid driven cavity (C. Migeon et al, 1999 and 2002) and (C. Migeon, 2002), side flow type (M. Guala et al, 2008) which experiments based on rotating disc to generated rotating flows and flow past cavities (C. Ozalp et al, 2009) which uses a water channel that past a lid driven cavity.

The test rig build by J. R. Koseff and R.L. Street (1984) were build base on translational motion lid driven cavity flow experiments with water tank of 12.5mm thickness made of a high grade acrylic glass and the conveyer were made from thermally copper belt with thickness of 0.08mm supported on and driven by two rollers which have constant speed of two percents within a drift of 0.5 percents with a low drift and not considered as a disturbances.

Further experimentations conducted by H.S. Rhee et al (1984) in the same facilities which stated that the cavity has a 50mm wide in the directions of lid motions, a maximum depth D of 925mm (for the present experiments D=B= 150mm) and a span L of 450mm transverse to the direction of lid motion (L=3·B). The concept done by C. Migeon et al (1999 and 2002) uses a concept of vertical water tank with dimensions of $80\times100\times120\ cm^3$ capacity which made of altuglass which slides smoothly downward along a large fixed vertical plane acting as a lid.

The experimental flows in lid driven cavity in this experimental analysis were adopted through by experiments which have been done in by Alex Liberzone (2011). For this experimental setup benchmark is because of it uses a transitional flow movements and not oscillating flow movements but the cylinder rod for transferring velocity to the flow itself were adopted from other benchmark experimental setup which is from S.J. Tsorng et al (2005) which used a four cylindrical shape roller to regulates the flows velocities which later modified with three cylindrical shape roller.

2.3 REYNOLDS NUMBER.

Reynold number of 3200 and 10000 were experimented and compared by J.R. Koseff and R.L. Street (1984) but only in validations of particle flow experiments, while the same facilities were used by H.S. Rhee et al (1984) but different type of study were focus which is on the effect of Taylor-Gortler-like vortices which involve in startup flow instabilities which use Reynolds number of 1000 to 35,000.

C. Migeon et al (2000) stated that the cavity velocity were 1.8cm/s which is -1.8cm/s in magnitude directions, the experiments were done in oscillating movement which capable of generating Reynolds number of 1000 and not in the translational movements directions such as experiment done by J.R Koseff and R.L Street (1984), H.S Rhee (1984) and Alex Liberzone (2011).

2.4 LID DRIVEN CAVITITES SHAPE

J.R. Koseff and R.L. Street (1984) and H.S. Rhee et al (1984) used a length to wide ratio of 3:1 rectangular lid driven cavity. H.S. Rhee et al (1894) have modified the experiment where the lid experiments were covered with Styrofoam with a thickness of 25mm but with the same length to wide ratio lid driven geometries.

C. Migeon et al (2000) experimented on different lid driven cavity shape which uses a length to wide ratio of 2:1 to study the efficiency of mixing process of square, rectangular and semicircular lid driven geometric shape which the dimensions are stated in the research as 12.4cm in length and 6.2 cm in width whereas, other shape of lid driven cavity were studies in term of non-experimental form such as triangular lid driven cavities (E. Ertuk and O. Gorkol, 2007) and arc shape lid driven cavities (H. Mercan and K. Atalik, 2008) which considered as a benchmark in this experiments.

The Reynold numbers benchmarks were getting from numerical experiments for equilateral triangle done by Erhan Ertuk and Orhan Gorkol (2007) and H. Mercan and K. Atalik (2009).

Table 2.1: Reynolds number from various author taken as benchmarks.

Benchmark Sources	Type Of Lid Driven Cavity Shape	Benchmark Reynolds Number
Ertuk and Gorkol 2007	Equilateral Triangle	Re=1,100,350,500,1000 and 1750
Mercan and Atalik 2009	Semi Elipse	Re=1000, 1500, 5000 and 6600

2.5 QUANTITATIVE MEASUREMENTS

J.R. Koseff and R.L. Streets, (1894) uses DISA 55X modular optical-laser-Doppler-anemometer systems and data were sampled of 100Hz by HP 21000A data acquisition systems which have uncertainty of 1mm/s to 1 percent at 30mm/s. For Rhee et al, 1894 uses a 2W Spectra-Physics (Model 164-06) laser were beamed through a 1mm thick circular glass rod and the camera that were used is Pentax 35mm camera with exposure time four to eight seconds to determine the pathlines.

There are many particle imaging techniques which is used to do quantitative measurements such as dye filament emission techniques (C. Migeon et al, 1999 and 2002), stereo imaging techniques which is a part of particle image velocimetry system for quantitative measurements (S.J. Tsorng et al 2005 and 2007) which only involve in two dimensional analysis of flow topologies.

Most particle image capturing is done by particle image velocimetry or PIV which done by J.R. Koseff and R.L. Street (1984) and S.J. Tsorng et al (2005 and 2007) which is expensive to fabricate or re-create therefore a more suitable method is being adapted in order to view the particle flow.

There are also similar particle flows experiments but using a rigid sphere particles which have been conducted by S.J. Tsorng et al (2005 and 2007), and based on S.J. Tsorng et al (2005) the lid driven experiments stated that “ laser illuminations technique were inappropriate in tracking larger particle and one must work instead of visible solid particles of greater size” which lead to another experiments which uses a cavity to particle ratio of 3:1 (S.J. Tsorng et al,2007) and found that there are correlations with the two experiments (S.J. Tsrong et al, 2005 and 2007) based on qualitative measurements results and also computational results.

2.6 QUALITATIVE MEASUREMENTS

The particle consist in the lid driven cavity geometries also plays an important role in mimics the flow particle inside the lid driven cavity based on various geometries which water flow is not visible in naked eye and very difficult to capture.

J. R. Koseff and R. L. Street 1894 uses a combinations of thymol blue (blue color pH indicator) and rheoscopic liquid technique (crystalline micro-structures) whereas H. S. Rhee et al 1894 substitute the thymol blue method with liquid crystal methods which has a liquid crystal micro capsule (Liquid Crystal Slurry, Liquid crystal technology) which as the lid moves as the color intensity also differ according to the liquid crystal intensity and light diffractions (from red to blue), the light were use is the white light (H. S. Rhee et al 1984).

Particle tracking velocimetry which tracks the movements of particle flow and analyze them in a discrete manner to analyze the velocity profile, boundary layer formations and vortices especially toroidal vortices (J.R. Koseff and R.L. Street, 1894) and/or Taylor Goetler-like vortices (C. Migeon, 2002). Advance development in software and hardware were enabled in making three-dimensional tracking systems which explained in M. Guala et al (2008).

The particle effects in water were measured using either Kalmalrov length scales and/or Taylor microscales. The experimental study which researches by M. Guala et al (2008) which involve in using Kolmorov time scales which is later compared to Taylors microscales.

The camera ratio which usually situated at the center of lid driven cavity but only one experiments stated the locations of the camera which is at the center of cavity of the lid driven cavity with aspect ratio of 2:1 (C. Migeon et al, 1999).

2.7 PARTICLE INSERTIONS.

J.R. Koseff and R.L. Street 1984 recommended that the concentrations of particle in water by weight should be 0.1 percent or less which also have been taken into account by H. S. Rhee et al 1984 which uses an even lesser concentrations which is 0.02 percent.

Experiments that uses a dye filament techniques which uses a 5mm in length located at downstream wall cavity grove tooled and a 2mm located downstreams the upper corner thin ribbon to emits particle streaks into waters and later capture using charge couple devices (C. Migeon et al 2000 and 2002) is one of a way to analyze particle flow without disturbing the water properties.

Particle insertions done by S.J. Tsorng (2007) explained that the particle is submerged inside the water glycerin solutions for a period of time before the experiment started and C. Ozalp et al (2010) conducted an experiments which base on flow past lid driven cavities which lead to an idea of the benchmark for the time for particle insertions which more than 12s for the flow to runs and become steady.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter it will discuss on how the experiment set up such as test rig design, lid driven geometry, lid riven rig, camera settings and control settings. The experimental analysis was done based on others previous experimentations based on lid driven cavity.

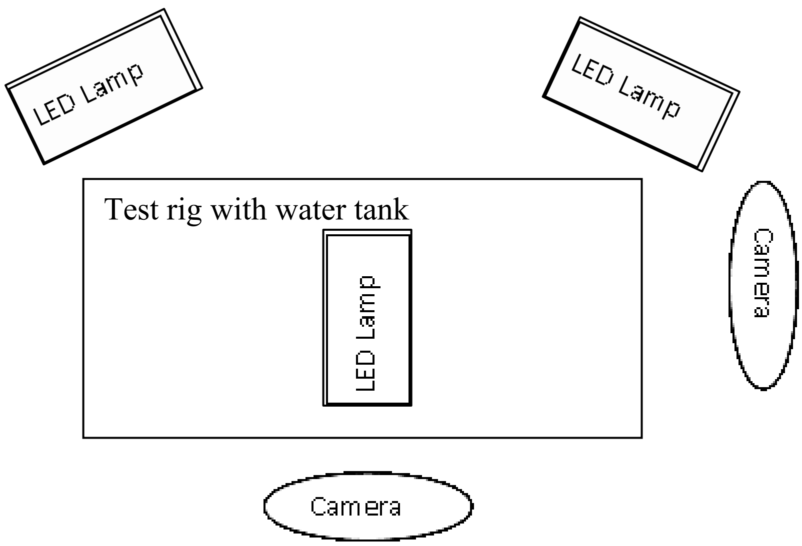

Figure 3.1: Layout overview of overall experimental setup

3.2 FLOW CHART

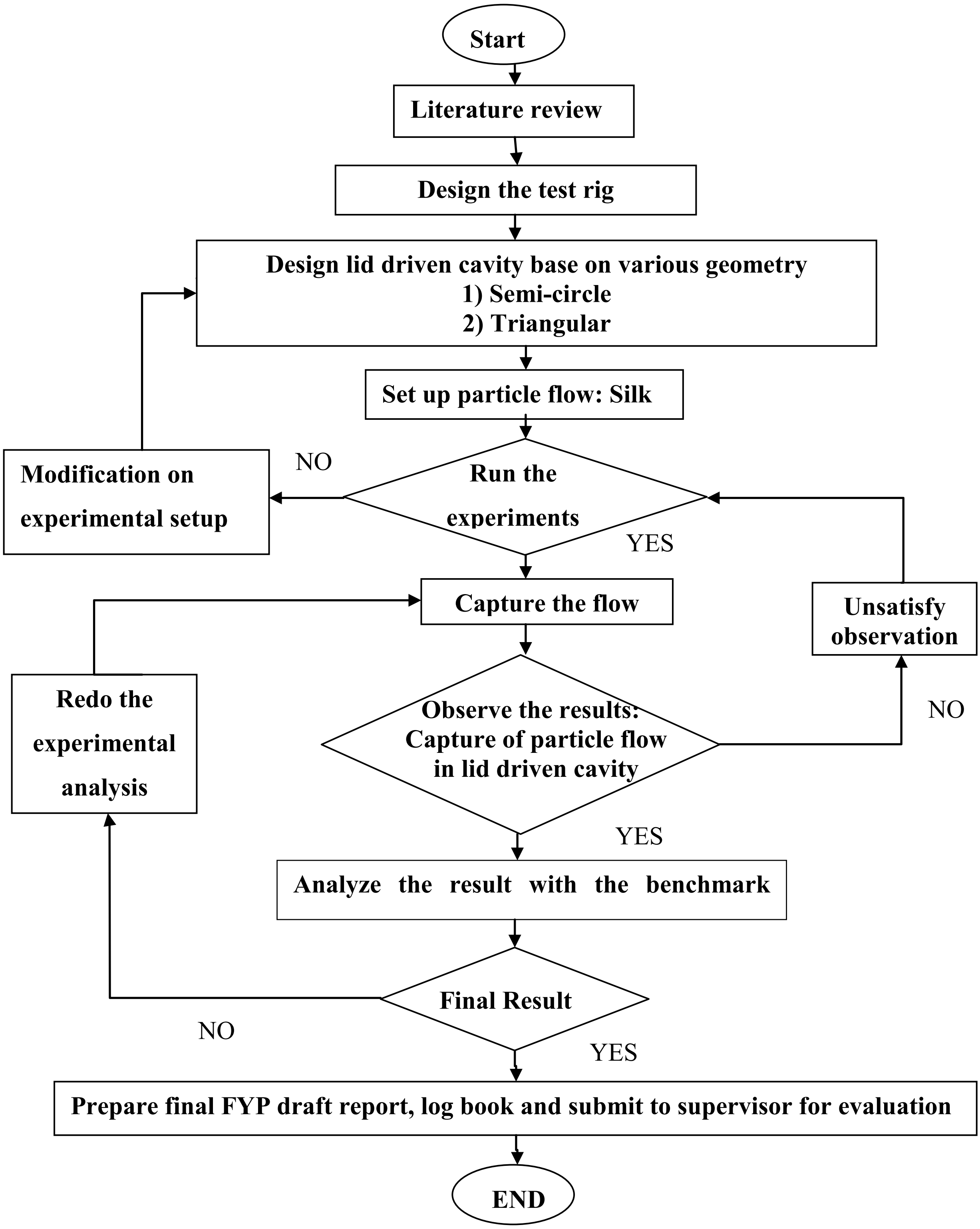

Figure 3.2: Flow chart for overall experiments.

3.3 EXPERIMENT DESIGN

The roller experimental setup was done as similar in S.J Tsorng et al (2005 and 2007) experimental setup and A. Liberzone (2011) experimental roller setup. The belt is tightened tightly for consistent flow (S.J Tsorng 2005) and the roller is situated between the inner parts of lid driven cavity.

The water tank which have dimension of 46cm height x 46cm wide x 93cm long glass container which have thickness of 1cm were used for water flow cavities.

Lighting were set up using 3 LED lamp with a frequency of 60Hz to avoid blinking or blur image during capturing the images and the environment lighting are made dimmer so that the camera can focus clearly on the lid driven cavity. 1 were place horizontally below the water tank and the other 2 were directed towards the center from left and right side of the water tank. The full view of experimental setup consists of 2 cameras from the side and 3 LED lamps are situated in **Figure 3.1**.

Figure 3.3: Experimental setup during experiments