PERFORMANCE EVALUATION OF ELECTRICAL DISCHARGE MACHINE ON TITANIUM ALLOY USING COPPER IMPREGNATED GRAPHITE ELECTRODE

MOHD HALIMUDIN BIN MOHD ISA @ HAMID

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First of all, all the praises and thanks be to Allah S.W.T for His Love,
This thesis is dedicated to my family,
To my beloved parent,
Maimunah Hj Abdullah,
My supportive wife,
Amizah Abdul
My wonderful brothers and sisters,
Hamnah Mohd Isa, Mohd Helmi Mohd Isa, Huda Mohd Isa
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ABSTRACT

Electrical discharge machining (EDM) which is very prominent amongst the non conventional machining methods is expected to be used quite extensively in machining titanium alloys due to the favorable features and advantages that it offers. This thesis presents the EDMing of titanium alloy (Ti-6246) using copper impregnanted graphite electrode with diameter of 8 mm. The main purpose of this study was to investigate the influenced of various parameters involved in EDM on the machining characteristics, namely, material removal rate (MRR), electrode wear ratio (EWR), surface roughness (Ra) and overcut.

In this investigation, the machining trials were performed using a Sodick linear motor EDM sinker series AM3L The experimental plan for the processes were conducted according to the design of experimental (DOE) and the results were statistically evaluated using analysis of variance (ANOVA). Results showed that current was the most significant parameter that influenced the machining responses on EDM of Ti-6246.

Confirmation tests were also conducted for the selected conditions for each machining characteristics in order to verify and compare the results from the theoretical prediction using Design Expert software and experimental confirmation tests. Overall, the results from the confirmation tests showed that the percentage of performance was acceptable due to all results obtained were within the allowable values which was less than 15% of marginal error.

ABSTRAK

Proses pemesinan nyahcas elektrik (EDM) yang agak dominan di antara proses pemesinan bukan konvensional dijangkakan akan bertambah meluas penggunaannya disebabkan sifat-sifat dan kelebihan yang dihasilkan keatas bendakerja. Kajian yang dijalankan ini adalah mengenai pemesinan EDM *sinker* terhadap bahan aloi titanium (Ti-6246) dengan menggunakan *copper impregnanted graphites* yang berdiameter 8 mm sebagai elektrod. Tujuan utama kajian ini adalah untuk mengkaji kesan beberapa parameter yang terlibat dalam EDM proses terhadap kriteria pemesinan seperti kadar pembuangan bahan (MRR), nisbah kehausan elektrod (EWR), kekasaran permukaan (Ra) dan ‘*overcut*’.

Dalam kajian ini, pemesinan yang dijalankan ke atas titanium dilakukan menggunakan *Sodick linear motor EDM series AM3L*. Ujian pemesinan untuk kedua-dua proses telah dinilai secara statistik menggunakan analisa variasi (ANOVA). Keputusan menunjukkan arus lektrik merupakan parameter yang paling signifikan yang mempengaruhi tindak balas pemesinan EDM ke atas Ti-6246.

Ujikaji pengesahan juga telah dijalankan bagi tujuan pengesahan dan perbandingan keputusan di antara nilai ramalan teori menggunakan perisian *Design Expert* dengan nilai yang diperolehi dari ujikaji. Secara keseluruhan, keputusan pengesahan ujikaji menunjukkan bahawa kesemua peratusan ralat perbezaan yang diperolehi berada di dalam lingkungan nilai yang dibenarkan iaitu peratus ralat kurang daripada 15%.

CONTENTS

CHAPTER **TITLE** **PAGE**

DECLARATION ii
ACKNOWLEDGEMENT iv
ABSTRACT v
ABSTRAK vi
CONTENTS vii
LIST OF TABLES x
LIST OF FIGURES xii
NOMENCLATURE xiv
LIST OF APPENDICES xv

1 INTRODUCTION
1.1 Overview 1
1.2 Background of Research 2
1.3 Statement of the research problem 4
1.4 Research Question 4
1.5 Objectives 4
1.6 Scope of study 5

2 LITERATURE REVIEW
2.1 Introduction 6
2.2 Electric Discharge Machining (EDM) 7
  2.2.1 Principle EDM Spark Erosion 8
  2.2.2 Machining Parameter 10

2.2.3 Electrode 10
    2.2.3.1 Key Factors of Electrode Material Selection 11
    2.2.3.2 Material Removal Rate (MRR) 11
    2.2.3.3 Electrode Wear Rate (EWR) 11
    2.2.3.4 Surface Roughness (SR) 12
    2.2.3.5 Machinability 12
    2.2.3.6 Material Cost 13
    2.2.3.7Graphite Electrode 13
2.2.4 Flushing 14
2.2.5 Dielectric Fluid 17
2.3 Machining Characteristics 17
2.3.1 Material Removal Rate 17
2.3.2 Electrode Wear Rate, EWR 18
2.3.3 Surface Roughness, SR 19
2.4 Titanium Alloys and Their Machinability 20
2.4.1 Introduction 20
2.4.2 Classification of Titanium Alloys 22
    2.4.2.1 Commercially pure (CP) titanium (unalloyed) 23
    2.4.2.2 Alpha and near-alpha alloys 23
    2.4.2.3 Alpha-beta Alloys 24
    2.4.2.4 Beta alloys 24
2.4.3 EDM of Titanium Alloys 25
    2.4.3.1 Machining Titanium Alloys with EDM 25
2.5 Design of Experiment (DOE) 26
2.5.1 Two-level Fractional Factorial Design 27
2.5.2 Response Surface Methodology (RSM) 28
2.5.3 Test of Statistical Significance 28

3 RESEARCH DESIGN

3.1 Introduction 30
3.2 Research Design Variables 30
3.2.1 Response Parameters 31
3.2.2 Machining Parameters 31
3.2.3 Workpiece Material 32

3.2.4 Electrode Material 33
3.2.5 Machine and Equipment 34
3.3 Analysis 39
3.3.1 Statistical Analysis 39
3.3.2 Metal Removal Rate (MRR) Measurement 40
3.3.3 Electrode Wear Rate (EWR) Measurement 41
3.3.4 Surface Roughness Measurement 42
3.3.5 Measurement of Hole Diameter 42
3.3.6 Experimental Design 43

4 RESULT AND ANALYSIS

4.1 Introduction 46
4.2 Experimental Results 47
4.3 Result Analysis 48
4.3.1 Analysis Results for Material Removal Rate, MRR 49
4.3.2 Analysis Results for Electrode Wear Rate, EWR 56
4.3.3 Analysis Results for Surface Roughness, SR 61
4.3.4 Analysis Results for Overcut 64
4.3.5 Analysis with Central Composite design 70

5 DISCUSSION

5.1 Introduction 86
5.2 Material removal rate, MRR 87
5.3 Electrode wear rate EWR 87
5.4 Surface roughness, SR 88
5.5 Overcut 89
5.6 White layer 89

6 CONCLUSIONS

6.1 Introduction 91
6.2 Conclusion 91

REFERENCES 93
APPENDICES 97

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Physical and mechanical properties of elemental titanium	21
2.2	Some commercial and semicommercial grades and alloy titanium	22
3.1	Machining parameters	31
3.2	The composition of Ti-6246	32
3.3	Mechanical Properties of Ti-6246	33
3.4	Typical Value for copper impregnanted graphite	34
3.5	Factor and level for EDM of Ti-6246	43
3.6	Two level full Factorial experiment with four factor and four center point	44
3.7	Experimental plan for EDM of Ti-6246	45
4.1	Experimental results for EDM of Ti-6246	47
4.2	ANOVA table for MRR in EDM process	51
4.3	ANOVA table for EWR in EDM process	57
4.4	ANOVA table for SR in EDM process	61
4.5	ANOVA table for Overcut in EDM process	65
4.6	Summary of significant factors in EDM experiments	70
4.7	Experimental plan for EDM of Ti-6246 (CCD)	71
4.8	Response results for EDM of Ti-6246 (CCD)	72
4.9	ANOVA table for response surface quadratic model for MRR in EDM of Ti-6246	73
4.10	ANOVA table after transformation for MRR in EDM of Ti-6246	74
4.11	Final ANOVA for EWR in EDM of Ti-6246	77
4.12	Final ANOVA for SR in EDM of Ti-6246	79
4.13	Final ANOVA for overcut in EDM of Ti-6246	81

4.14 An example of output from the point prediction tool EDM of Ti-6246 83
4.15 Analysis of confirmation experiments for MRR in EDM process 84
4.16 Analysis of confirmation experiments for EWR in EDM process 84
4.17 Analysis of confirmation experiments for SR in EDM process 84
4.19 Analysis of confirmation experiments for Overcut in EDM process 84

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Classification of EDM processes	7
2.2	Types of EDM processes	8
2.3	Spark gap	8
2.4	Phase of electrical discharges	9
2.5	Ignition of the first discharge	15
2.6	The particles created	16
2.7	The additional particle density	16
3.1	Sodick AM3L	35
3.2	Mitutoyo Formtracer CS-5000 surface roughness tester	35
3.3	Zeiss – Coordinate Measuring Machine (CMM)	36
3.4	Precisa Balance	36
3.5	Buehler automatic mounting machine	37
3.6	Grinder and Polisher	38
3.7	Optical microscope	38
3.8	Flowchart outlining the analysis steps undertaken	40
4.1	Pareto Chart for significant effect choosed (MRR)	49
4.2	Normal probability plots of residuals for MRR in EDM process	52
4.3	Residual vs predicted response for MRR in EDM process	52
4.4	Residual vs run number response for MRR in EDM process	53
4.5	Interaction between Peak Current (A) and Pulse on time (C)	54
4.6	Interaction between Peak Current (A) and Pulse on time (D)	54
4.7	Interaction between Pulse on time (C) and Pulse off time (D)	55
4.8	Perturbation plot for MRR in EDM process	56

4.9 Normal probability plots of residuals for EWR in EDM process 58
4.10 Residual vs predicted response for EWR in EDM process 58
4.11 Residual vs run number response for EWR in EDM process 59
4.12 Interaction between Peak Current (A) and Servo Voltage (B) 60
4.13 Interaction between Peak Current (A) and Pulse Off Time (D) 60
4.14 Normal probability plots of residuals for SR in EDM process 62
4.15 Residual vs predicted response for SR in EDM process 63
4.16 Residual vs run number response for SR in EDM process 63
4.17 Interaction between Peak Current (A) and Pulse On Time (C) 64
4.18 Normal probability plots of residuals for overcut in EDM process 66
4.19 Residual vs predicted response for overcut in EDM process 67
4.20 Residual vs run number response for Overcut in EDM process 67
4.21 Interaction between Peak Current (A) and Pulse On Time (C) 68
4.22 Interaction between Peak Current (A) and Pulse On Time (D) 69
4.23 Interaction between and Pulse On Time (C) and Pulse Off Time (D) 69
4.24 Normal probability plots of residuals for MRR in EDM process (CCD) 75
4.25 Residual vs predicted response for EWR in EDM process (CCD) 76
4.26 3D response surface for MRR in EDM process (CD) interaction 76
4.27 3D response surface for MRR in EDM process (AD) interaction 77
4.28 One factor plot for EWR in PMD-EDM process 78
4.29 One factor plot for Overcut in PMD-EDM process 80
4.30 Pulse off time (D) plot for Overcut in PMD-EDM process 80
4.31 3D response surface for Overcut in EDM process (CD) interaction 82
4.32 3D response surface for Overcut in EDM process (AD) interaction 82
5.1 White layer with lower pulse on current 90
5.2 White layer with higher pulse on time 90

LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	-	Analysis of variance
CCD	-	Central composite design
CMM	-	Coordinate measuring machine
EDM	-	Electro discharge machining
EWR	-	Electrode wear rate
EWW	-	Weight of electrode used
MRR	-	Material/metal removal rate
RSM	-	Response surface methodology
SR	-	Surface Roughness
Tm	-	Machining times
Wa	-	Weight of workpiece after machining
Wb	-	Weight of workpiece before machining
WRW	-	Weight of workpiece used
x1,x2, x3,…,xk	-	Input variables
α	-	Alpha phase
β	-	Beta phase

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A-1	Workpiece preparation plan	97
A-2	Actual workpiece preparation	97
A-3	Electrode preparation	98
A-4	Electrode and Workpiece for experiment	98
B-1	Program For hole makking on EDM die sinking (AM3L)	99
C-1	Experimental results for EDM of Ti-6246 (two level full factorial)	100
C-2	Experimental results for EDM of Ti-6246 (CCD)	101
D-1	Unmodified ANOVA table for MRR in EDM process	102
D-2	Box Cox Plot for MRR in EDM process	103
E-1	Ra reading for sample run 18	104
F-1	White layer for low and high MRR	105
F-1	White layer for low and high Ra	105
F-1	White layer for low and high Overcut	106
F-1	White layer for low EWR	106

CHAPTER 1

INTRODUCTION

1.1 Overview

The use of light, thin and compact mechanical elements has recently become a global trend. The search for new, lightweight material with greater strength and toughness has led to the development of new generation of materials such as titanium and nickel alloys, although their properties may create major challenges during machining operations. Having greater hardness and reinforcement strength, these materials are difficult to machine by the traditional methods. Although these materials can be machined conventionally, sub surface damages such as metallurgical alterations, work hardening, delimitation and microcracks and others can occur under certain circumstances which cause a detrimental effect on the performance of the machined component. Since the cost of using conventional machining is generally prohibitive, non-conventional machining such as electric discharge machining (EDM) and laser machining probably amongst the ideal technique in dealing with these materials.

Most titanium alloys and component design characteristics make them expensive to be machined and historically, titanium has been perceived as a material that is difficult to machine (Ezugwu, E.O and Wang, Z.M. 1997). Due to titanium's growing acceptance in many industries, along with the experience gained by progressive fabricators, a broad base of titanium machining knowledge is now exist. It was reported that commercially pure grades of titanium [ASTM B, Grades 1, 2, 3, 4] (ASM International, 1988) can be machined much easier than aircraft alloys.

Although titanium alloys is tough it can experienced sub-surface damaged during machining operations. Damage appears in the form of microcracks, built up edge, plastic deformation, heat affected zones and tensile residual stresses **(**Sharif, 1999; and Hong *et al*., 2001**)**. In service, these can lead to degraded fatigue strength and stress concentration.

Non-traditional machining of metal removal such as EDM expected to be used extensively years to come, because it’s favorable results. It is particularly useful for rapid removal of metal of free form surface or complex shaped parts, thin sections, and from large areas down to shallow depths. This process has less damaging effect on the mechanical properties of the metal (Rival, 2005).

1.2 Background of Research

EDM is a non-traditional concept of machining which has been widely used to produce dies and molds. It is also used for finishing parts for aerospace and automotive industry and surgical components. This technique has been developed in the late 1940s (Norliana Mohd Abbas *et al*., 2006).where the process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of a dielectric fluid (Norliana Mohd Abbas *et al*., 2006).

This process is finding an increasing demand owing to its ability to produce geometrical complex shapes as well as its ability to machine hard materials that are extremely difficult to machine when using conventional process. EDM has proved its capability especially in the machining of super tough, hard and electrically conductive materials such as the new space age alloys (Rival, 2005). The process variables include not only the electrical but also non-electrical parameters, which have received quite a substantial amount of research interest.

Optimum selection of process parameters is very much essential, as this is a costly process to increase production rate considerably by reducing the machining time. Several researchers carried out various investigations for improving the process performance. As EDM is a very complex and stochastic process, it is very difficult to determine optimal parameters for best machining performance, i.e., productivity and accuracy (T. A. El-Taweel, 2009). Material removal rate, tool wear, surface finish and also overcut are most important output parameters, which influence the cutting performance. But these performance parameters are conflicting in nature. The higher the MRR, the better, whereas the lower the tool wear, the better. In a single objective optimization, there exists only one solution. But in the case of multiple objectives, there may not exist one solution, which is the best with respect to all objectives. In EDM process, it is difficult to find a single optimal combination of process parameters for the performances parameters, as the process parameters influence them differently. Hence, there is a need for a multi-objective optimization method to arrive at the solutions to this problem.

The published literature indicates that few studies have been reported for the optimization of process parameters in EDM. Therefore, this study is aims at investigating the best performance of various input process parameters in EDM die-sinking process of Ti-6246. Further, no technology tables or charts are available for EDM of titanium alloy (Ti-6246) using copper graphite electrode. Therefore, it is imperative to develop a suitable technology guideline for appropriate machining of Ti-6246. Electrodes with copper graphite, peak current, servo voltage, pulse on time and pulse off time are considered as input EDM machining parameters. The process performance such as material removal rate (MRR), surface roughness (SR), overcut and electrode wear rate (EWR) were evaluated.

1.3 Statement of the research problem

How does a new developed electrode performed when EDM alpha beta titanium alloy Ti-6246 with respect to material removal, electrode wear, dimensional hole accuracy and surface finish.

1.4 Research Question

a. What are the machining parameters that influence the EDMing of Ti-6246 using copper impregnanted graphite electrode.
b. What are the significant parameters that influence to the responce during EDM of Ti-6246.
c. What correlations exist among the parameters and machining responses and also how to quantify.
d. What mathematical model is suitable to represent the performance evaluation of EDMing Ti-6246.

1.5 Objectives

The objectives of the study are:

a) To evaluate the performance of copper Impregnated graphite electrode when Electro-Discharge Machining Ti-6246 with respect to various machining responses.

b) To determine the significant parameters that influences the machining responses during Electro-Discharge Machining of Ti-6246.
c) To establish mathematical model for the MRR, EWR and surface finish during EDM of Ti-6246 using DOE approach.

1.6 Scope of study

a) Machining responses to be investigated are material removal rate (MRR), electrode wear rate (EWR), surface roughness (SR) and overcut.
b) Electro-Discharge Machining (Die sinking) AM3L SODICK will be employed.
c) Alpha-beta alloy, Ti 6Al 2Sn 4Zr 6Mo (Ti-6246) will be selected as workpiece material.
d) Copper impregnated graphite will be used as the EDM electrode.
e) Kerosene will be used as the dielectric fluid.

SIMULATIONS OF SOLID PARTICLE IN A LID-DRIVEN CAVITY FLOW USING LATTICE BOLTZMANN METHOD

MUHAMMAD AMMAR BIN NIK MU’TASIM

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To my beloved Parents,

Nik NorHayati binti Nik Abdul Kadir , Nik Mu'tasim Nik Abdul Rahman, my Siblings& friends

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ABSTRACT

The purpose of this study is to investigate the behaviour of a solid particle suspended in a two-dimensional viscous flow. The flow considered takes place in a closed square cavity, driven along its upper face by a translating lid. Second order upwind Lattice Boltzmann method computations are performed to characterize the fluid flow. The center locations of the fluid flow are first being track to simulate the path of the solid particle before the particle are introduced. The particle phase was modelled using the Lagrangian–Lagrangian (L–L) approach where the solid particles are treated as points moving in the computational domain as a result of the fluid motion. Slightly buoyant solid particle are then inserted in the cavity with flow at steady state condition. Different cases were considered, where the Reynolds number of the flow ranging in 130, 470, 860 and 3200 were used. The calculated solid particle motions are then compared with slightly denser particle with Reynolds number of 470. The results obtain shows that the slightly denser particle tends to move slightly downwards in the two-dimension cavity than the slightly buoyant particle. Solid particle trajectories are otherwise found to align closely with center location of the transient flow. The solid particle orbits, however, are not evenly distributed within the cavity, and gathered closer to the edge of the cavity as the Reynolds and Stokes numbers increase.

ABSTRAK

Kajian in dilakukan bertujuan mengkaji kesan zarah pepejal tergantung di dalam aliran tepu dua dimensi. Aliran ini dilaksanakan didalam sisipan segi empat tepat rongga persegi dua dimensi dengan penutup bergerak. Persamaan ‘Second order upwind’ dengan Kaedah Lattice Boltzmann computasi dijalankan untuk menentukan ciri-ciri aliran bendalir. Lokasi pusat bagi aliran bendalir pertama di kesan bagi menjalankan simulasi pergerakan zarah pepejal sebelum zarah pepejal di masukkan kedalam rongga segi empat tepat. Fasa zarah pepejal di modelkan menggunakan kaedah ‘Lagrangian–Lagrangian (L–L)’ dimana zarah pepejal ini di definasikan sebagai titik yang bergerak didalam ruang komputasi akibat kesan daripada pergerakan bendalir. Zarah pepejal yang menghampiri ringan bendalir kemudiannya dimasukkan kedalam rongga persegi dengan bendalir bergerak di dalam keadaan stabil. Beberapa kes telah di ambil kira, dimana penggunaan number Reynolds 130, 470, 860 dan 3200 digunakan. Pergerakan zarah pepejal yang telah dikaji kemudiannya dibandingkan dengan zarah pepejal yang sedikit lebih berat dengan menggunakan number Reynolds 470 untuk perbandingan. Keputusan yang diperolehi menunjukkan zarah pepejal yang sedikit lebih berat mengalami penurunan sedikit kebawah di dalam rongga segi empat dua dimensi berbanding zarah pepejal yang sedikit ringan daripada bendalir. Pergerakan zarah pepejal selainnya menunujukan trend yang sama dengan pergerakan lokasi pusat aliran bendalir. Walaubagaimanapun, orbit zarah pepejal menunjukkan pembahagian yang berlainan didalam rongga segiempat tepat dan mengelilingi bahagian hujung bucu pada sisi empat rongga apabila nombor Reynolds dan nombor Stokes meningkat.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	DECLARATION		**ii**
	DEDICATION		**iii**
	ACKNOLEDGEMENT		**iv**
	ABSTRACT		**v**
	ABSTRAK		**vi**
	TABLE OF CONTENTS		**vii**
	LIST OF TABLES		**x**
	LIST OF FIGURES		**xi**
	LIST OF SYMBOLS		**xii**
	LIST OF APPENDICES		**xiv**
1	**INTRODUCTION**		
	1.1	Introduction	1
	1.2	Lattice Boltzmann Method	3
	1.3	Comparison between Traditional CFD and Lattice Boltzmann Method	4
	1.4	Advantages of Lattice Boltzmann Method	4
	1.5	Lid-Driven Cavity and Fluid Particle Flows	5

1.6 Objectives 6
1.7 Scopes 6

2 LATTICE BOLTZMANN METHOD
2.1 Lattice Boltzmann Equation 8
2.2 Boltzmann Collision Operator 9
2.3 Bhatnagar-Gross-Krook (BGK) Collision Model 10
2.4 Time Relaxation 11
2.5 Lattice Boltzmann Equation with BGK 12
2.6 Boundary Conditions 14
2.7 Isothermal Lattice Boltzmann Model 15

3 SOLID PARTICLES IN LID-DRIVENCAVITY FLOW
3.1 Introduction 17
3.2 Fundamental Theory 18
3.3 Particle Characteristics 19
3.4 Behavior of Solid Particles in Lid-Driven Cavity Flow 22
  3.4.1 Influence of Reynolds Number 25
  3.4.2 Influence of Particle Size 25
  3.4.3 Influence of Particle Rotation 26

4 METHODOLOGY AND CODE VALIDATION
4.1 Methodology 27
4.2 Flow Chart 29
4.3 Code Validation Analysis 30
  4.3.1 Transient Flow of Lid-Driven Square Cavity 30
  4.3.2 Particle Trajectory in a lid-driven square cavity 35

5 RESULT AND DISCUSSION

5.0 Results 37

5.1 Single Particle in 2-D flow for slightly buoyant solid particle 38

5.1.1 Reynolds number 130 38

5.1.2 Reynolds number 470 39

5.1.3 Reynolds number 860 40

5.1.4 Reynolds number 3200 41

5.2 Single Particle in 2-D flow for slightly denser solid particle 42

5.3 Comparison between simulations using LBM and N-S equation by S.J. Tsrong 44

6 CONCLUSION AND RECOMMENDATIONS

Conclusion and Recommendations 46

REFERENCES 47

APPENDIX 50

LIST OF TABLES

TABLE NO	TITLE	PAGE
1.1	Comparison between N-S and LBM	4

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
2.1	Time relaxation concept	12
2.2	Free slip boundary condition	14
3.1	Particle size	21
3.2	Comparison of particle trajectory and passive tracers	23
3.3	Location of one particle for Re 1000 using Navier Stokes Equation	24
4.1	Flow chart	28
4.2	LBM flow chart	29
4.3	Geometry of square driven cavity	31
4.4	Stream functions in cavity flow at *R*e 400	32
4.5	Center location trajectory for *R*e 130 to *Re* 7500	34
4.6	Center location trajectory for *R*e 10000	35
4.7	Particle Trajectory for *Re* 130	36
5.1	Particle Movement for *Re* 130	38
5.2	Particle Movement for *Re* 470	39
5.3	Particle Movement for *Re* 860	40
5.4	Particle Movement for *Re* 3200	41
5.5	Comparison of Slightly buoyant particle and slightly denser particle	43
5.6	Large scale comparison	43
5.7	Comparison N-S vs LBM	44

LIST OF SYMBOLS

SYMBOLS

a	Acceleration
D	Dimension
E	Energy
$f(\mathbf{x},\mathbf{c},t)$	Density distribution function
f_i	Discretized density distribution function
f_i^{eq}	Discretized equilibrium density distribution function
$F_{f,g}$	External force
g	Gravitional force
g_i	Discretized internal energy distribution function
g_i^{eq}	Discretized equilibrium internal energy distribution function
x	Characteristic length
P	Pressure
Q	Collision operator
t	Time
u	Horizontal velocity
$\mathbf{u}$	Velocity vector
U	Horizontal velocity of top plate
$\mathbf{x}$	Space vector
w	Weight coefficient
	Stress in fluid

Computational Symbols

υ	Dynamic shear
ν	Kinematic viscosity
α	Thermal diffusivity
μ	Viscosity
ρ	Density
τ	Time relaxation
χ	Thermal diffusivity
Ω	Collision operator

Abbreviations

BGK	Bhatnagar-Gross-Krook
CFD	Computational Fluid Dynamics
D2Q9	Two Dimensions Nine Velocities
FE	Free Energy
FEM	Finite Element Method
LB	Lattice Boltzmann
LBE	Lattice Boltzmann Equation
LBM	Lattice Boltzmann Method
LGA	Lattice Gas Approach
PDEs	Partial Differential Equations
2-D	Two Dimensions
3-D	Three Dimensions

Non-dimensional parameter

Re	Reynolds number
St	Stokes Number

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Stream function In lid Driven cavity	50
B	Codes for One Particle Movement	53
C	Codes for Center Location Transient Movement	71

CHAPTER 1

INTRODUCTION

1.1 Introduction

Governing equations for fluid flow can be described by three equations which is continuity, momentum and energy equation. The famous incompressible Navier-Stokes equation represents a local conservation law for the momentum in the system. This equation only partially addresses the complexity of fluids in engineering applications. The equation is so complex that currently there is no analytical solution except for a small number of special cases [1].

To solve the Navier-Stokes equation numerically is very challenging task. The only reliable information pertaining to a substantial process of fluid dynamics is usually given by an actual experiment using full scale equipments. However, in most cases, such experiment would be very costly and often impossible to conduct [1].

In order to simulate fluid flows using computer, continuity equation and the famous Navier-Stokes equation need to be solved with infinite accuracy. Researchers and engineers need to discretise the problem by using a specific method before they can solve the problem.

As years passes by, high speed digital computers were developed. Researchers gain new essential tools that can solve engineering problems using computational methods called Computational fluid Dynamics. Computational Fluid Dynamic (CFD) is a powerful tool in simulating fluid flow problems. Some CFD technique such as Finite Difference Method, Finite Element Method and Finite Volume Method are used nowadays by computer simulations to solve the Navier-Stokes equation numerically.

The numerical simulation begins with creating a computational grid. Grid is the arrangement of these discrete points throughout the flow field [2]. Depending on the method used for the numerical calculation, the flow variables are either calculated at the node points of the grid or at some intermediate points as well. The spacing between grid points requires a fine space in order to attain a high degree of accuracy. However, this requires more computer memory which means more computational time is required.

A rectangular lattice with fixed spacing between node points in each dimension is the simplest computational grid. Apart from that, there are a number of methods that use unstructured grids where the density of the node points is not constant throughout the regions. The density is higher when higher accuracy is required in the specified region.

Within recent years, A new method called the lattice Boltzmann method (LBM) has engrossed much attention in computational fluid dynamics. LBM has emerged as a powerful and alternative approach in solving various fluid flow phenomena.

1.2 Lattice Boltzmann Method

Many methods have been introduced such as the finite difference, finite element, and finite volume technique for solving Navier stokes equation. Another different approach to the usual computational fluid dynamics (CFD) is the Lattice Boltzmann Method (LBM). LBM has been established to be successful in simulations of fluid flow and other types of complex physical system such as in porous media [3] and turbulence [4]. It is also capable for simulating multiphase and multi component fluid flow involving complex interfacial dynamics. It is a discrete computational method based on the Boltzmann equation that was improved from lattice gas automata (LGA).

The main idea of the Lattice Boltzmann Method is to produce simplified kinetic models that integrate the critical physics of microscopic processes so that the macroscopic averaged properties meet the terms with the desired macroscopic Navier-Stokes equations. In other words, the objective is to derive the macroscopic equations for the microscopic dynamics in terms of statistics rather than solving the macroscopic equations. The concept of particle distribution has been developed in the field of statistical mechanics to describe the kinetic theory of liquids and gases.

The single-particle distribution is then applied in the lattice Boltzmann scheme. The degree of freedom for particle distribution was reduced from the substantial world to a computationally controllable numeral in the simulation while still maintaining dependability with the range treatment of the substantial world.

1.3 Comparison between Traditional CFD and Lattice Boltzmann Method

Table 1 below shows one major comparison between Traditional CFD and Lattice Boltzmann Method (LBM):-

Table 1.1: Comparison of Traditional CFD and LBM

Traditional CFD	**Lattice Boltzmann Method (LBM)**
• Traditional CFD generally starts from non linear partial differential equation (PDEs). These PDEs are then discretized either by finite differences, finite element finite volume or spectral methods. The result of discretization into Ordinary Differential Equations (ODEs) or algebraic equations are then solved by standard numerical methods.	• LBM generally starts from discrete microscopic model. It is constructed by deriving corresponding macroscopic equations using multi-scale analysis to preserve the desired quantities for example the mass and momentum for Navier-Stokes equation.

1.4 Advantages of Lattice Boltzmann Method

There are several advantages of using Lattice Boltzmann method. The list below shows the advantages of Lattice Boltzmann Method comparing to the traditional CFD method:-

i) The algorithm is simple and can be apply with a kernel of just a few hundred lines and modified to fit application such as complex simulations.

ii) Allows an efficient parallelization of the simulations even on parallel machines with moderately slow interconnection system due to the regular lattice and to the simply limited dynamics that involve only a contact of each lattice node with its nearest neighbor nodes at each iteration step.

iii) LBM is useful for applications such as multiphase flows, where as the two phases can represent with the same fluid model. The interface between the phases is handled automatically as an element for the model. Different news though for the traditional CFD, a PDE has to be written down for each of these two phases, as well as for the interaction of the phases on its frequent interfaces. This execute of this PDE model will require an advanced software engineering method to track the position of the interface and executing its dynamics.

iv) The estimated advantage of LBM compared to conventional CFD is that, no discretization of the macroscopic continuum equations needs to be provided. Hence, the LBM does not need to consider explicitly the distribution of pressure on interfaces of refined grids since the implicitly is included in the computational scheme.

1.5 Lid-Driven Cavity and Fluid Particle Flows

Many Researchers has been focusing on lid driven cavity flow as the main research area ever since rotating flows of viscous fluids has been applied in various industrial applications. Although it is a simple geometry, but lid- driven cavity flow may involves in high degree of complexity. It is crucial for analyzing fundamental aspects of recirculation fluids.

The study of wall bounded fluid particle flows has been done by many researchers to represent industrial system for example the fluidized beds, pneumatic or slurry transport of powders, coal combustion, dust explosion, catalytic reactions and many other industrial applications.

Researchers such as Frank et al [5] simulated the motion of solid particles in a horizontal two-dimensional turbulent channel flow based on the lagrangian approach. P. Kosinski et al [6] did a study on the simulation of solid particles behavior in a driven cavity flow using the Eularian-Lagrangian approach while S.J Tsrong et al. [7] study the behavior of macroscopic rigid spheres in lid driven cavity flow experimentally. Yet still remain no research done with lattice Boltzmann method to study the behavior of particles in rotating fluid flows. Thus the main subject of this study is to investigate the behavior of the particles and the particle influence on the fluid using Lattice Boltzmann numerical scheme.

1.6 Objectives

The objective of this study is to develop a Lagrangian-Lagrangian based numerical scheme to simulate the behavior of solid particles in a lid driven cavity.

1.7 Scope

The scopes of this study are as follows:-

i) Implementing Lattice Boltzmann Method to simulate velocity and pressure fields

ii) By applying the Second Newton Law to trace the position of the solid particle in lid-driven cavity flow.

iii) By evaluating the behavior of solid particles in 2-D lid-driven cavity flow

iv) Evaluate the simulations using Reynolds Number ranging from 100 to 1000 and compare the obtained results using lattice Boltzmann scheme to the benchmark (where driven cavity is used as a benchmark) results gain in the literature (Navier-Stokes Schemes).