



**UNIVERSITI PUTRA MALAYSIA**

***DEVELOPMENT OF DUAL-PURPOSE DISC AGROCHEMICAL  
APPLICATOR FOR FIELD CROPS***

**MOHAMMED SHU'AIBU ABUBAKAR**

**FK 2011 96**

**DEVELOPMENT OF DUAL-PURPOSE DISC AGROCHEMICAL  
APPLICATOR FOR FIELD CROPS**

By

**MOHAMMED SHU'AIBU ABUBAKAR**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in  
Fulfillment of the Requirements for the Degree of Doctor of Philosophy**

**September 2011**

## DEDICATION

*This work is dedicated to my late mother (Hajiya Amina), father, (Alhaji Mohammed Olan Garba)  
wife (Maryam), and children (Al-Amin and Fatima)*



Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Doctor of Philosophy

**DEVELOPMENT OF DUAL-PURPOSE DISC AGROCHEMICAL  
APPLICATOR FOR FIELD CROPS**

By

**MOHAMMED SHU'AIBU ABUBAKAR**

**September 2011**

**Chairman: Desa Bin Ahmad, PhD, P.Eng**

**Faculty: Engineering**

The thesis focuses on design, fabrication, development and evaluation of a new dual-purpose disc agrochemical applicator for field crop to boost agricultural mechanization in food production and also to overcome the safety concern of hazardous spray drift from hydraulic nozzles during chemical application by the farmers. Small and large scale models of the new concept dual-purpose agrochemical applicator were successfully developed and evaluated. The small scale equipment was driven by variable rate DC motor and rheostat for disc rotary speed variation. The full scale model (for real application) was propelled by PTO shaft of a high clearance tractor using a step-up gear box for disc speed variation. The dual-purpose equipment's performances for both granular and liquid chemical application were reported. The performance of the equipment is highly dependent on some physical properties of the chemical to be applied such as density, coefficient of friction, size distribution, viscosity, surface tension as

well as prevailing weather conditions like air temperature and humidity. However, the effects of these physical properties were not reported in this study.

The dual-purpose agrochemical applicator was tested at application rates of 40 (low), 80 (median) and 120 kg/ha (high) as well as 50 (low), 100 (median) and 150 kg/ha (high) for the urea and NPK granular chemical fertilizers respectively. Rotary disc speed was varied at four different levels 550, 700, 850 and 1000 rpm with three different combinations of 2, 4 and 6-vane disc. Result suggests that the best granular distribution coefficient of uniformity ( $CU_G$ ) of 18% and 19% were achieved at median application rates 40 kg/ha and 50 kg/ha at 550 rpm disc speed and with 2-vane disc for urea and NPK respectively. The worst  $CU_G$  was obtained at 1000 rpm disc speed combined with 6-vane disc for the both fertilizers. An optimum average working width of 1.8 and 2.1 m in correspondence with  $CU_G$  values of 18 and 19% for urea and NPK granular fertilizer respectively were achieved.

HC amine 48 and NASA glyphosate liquid chemical solutions were each tested at application rates of 30 (low), 60 (median) and 90 l/ha (high) at four different rotary disc speeds of 2000, 3000, 4000 and 5000 rpm with three different diameter discs of 300, 400, 500 mm. Result shows that the average values of volume median diameter (VMD) range from 342-102  $\mu\text{m}$  and 344-108  $\mu\text{m}$  at 2000-5000 rpm rotational disc speed at different values of application rate for NASA glyphosate and HC amine 48 liquid chemicals respectively. The average value of the number median diameter (NMD) varies from 86 to 208  $\mu\text{m}$  and 82 to 209  $\mu\text{m}$  for NASA glyphosate and HC amine 48 liquid solution respectively. These values were determined in order to ascertain the liquid

solution spray characteristics. The average values for coefficient of uniformity of the droplet spectrum ( $CU_L$ ) expressed as VMD/NMD were found to be in the range from 1.25 to 1.63 and 1.22 to 1.65 for NASA glyphosate and HC amine 48 liquid chemicals respectively.

A comparison in terms of liquid chemical solution deposition between the new developed dual-purpose rotary disc chemical applicator and the results of commonly used conventional knapsack sprayer with flat fan pressure nozzles reported from literatures showed that the latter when operating at a disc speed of 5000 rpm and application rate of 90 l/ha was found to produce spray droplet size of 79% ranging 100-250  $\mu\text{m}$  compared to reported results of former with droplet size of 80% ranging 250-350  $\mu\text{m}$ . This indicates that the new concern application method can produce a narrower range of droplet size than the conventional hydraulic nozzles methods. Also liquid chemical application techniques producing larger droplets size may have unexpected application efficiency and environmental pollution. Lastly, results from the field experimental tests suggest that the average effective field capacity for the equipment on a prime mover was found to be 0.89 ha/hr or 7.12 ha/man-day for a 8 hour working day, when compared with the motorized mistblower knapsack sprayer and conventional knapsack sprayer with 0.35 ha/hr (2.8 ha/man-day) and 0.20 ha/hr (1.6 ha/man-day) respectively. This shows 4 and 6 times lower than when the new developed equipment was used for chemical application instead of motorized mistblower knapsack sprayer and conventional knapsack sprayer respectively. A benefit of an operational cost saving of RM7.7/ha (USD2.6/ha) and RM12.5/ha (USD4.2/ha) were revealed by using the new

developed equipment as compared with the use of motorized mistblower knapsack sprayer and conventional knapsack sprayer respectively.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMBANGUNAN CAKERA DWI-GUNA PENYEMBUR AGRO-KIMIA UNTUK TANAMAN LADANG**

Oleh

**MOHAMMED SHU'AIBU ABUBAKAR**

**September 2011**

**Pengerusi: Desa Bin Ahmad, PhD, P.Eng**

**Fakulti: Kerujuteraan**

Tesis ini memberi fokus kepada pembangunan dan penilaian “Alatan Aplikasi Bahan Kimia Cakera Dwifungsi” dalam penjenteraan tanaman lading bagi peningkatan hasil disamping mengurangkan kehilangan semburan bilamana semburan keluar dari muncung penyembur semasa kerja penyemburan dilakukan oleh pesawah. Model skala kecil dan skala besar yang menggunakan konsep penyemburan dwifungsi ini telah berjaya dibangun dan dinilai. Model alatan skala kecil dipacu oleh DC motor kadar berubah dan rheostat bagi perubahan kelajuan putaran piring. Model alatan skala penuh atau besar (untuk kegunaan sebenar) dipacu oleh Aci PTO Traktor Kelegaan Tinggi menggunakan Kotak Gear Peningkat untuk merubah kelajuan. Prestasi Alatan Dwifungsi untuk aplikasi bahan kimia berbutir dan bahan kimia cecair telah direkodkan. Prestasi alat bergantung pada sifat fizikal kimia yang digunakan seperti ketumpatan, pekali geseran, taburan saiz, kepekatan, tegangan permukaan, juga keadaan cuaca semasa seperti suhu udara dan kelembapan. Namun, kesan sifat fizikal tidak dilaporkan dalam kajian ini.



Alat Aplikasi Kimia Dwifungsi ini telah di uji pada kadar 40 (rendah), 80 (sederhana) dan 120 kg/ha (tinggi) untuk baja urea butiran, dan pada kadar 50 (rendah), 100 (sederhana) dan 150 kg/ha (tinggi) bagi baja NPK butiran. Putaran piring dilakukan pada empat peringkat kelajuan iaitu 550, 700, 850 dan 1000 psm dengan tiga kombinasi berlainan iaitu 2, 4 dan 6 sayap piring. Keputusan mencadangkan iaitu koefisi  $CU_G$  taburan butiran terbaik adalah 18% dan 19% diperolehi pada aplikasi kadar sederhana 40 kg/ha dan 50 kg/ha, pada kelajuan piring 2 sayap 550 psm untuk baja urea dan NPK, masing-masing.  $CU_G$  terburuk tercatat oleh kombinasi piring 6-sayap dengan kelajuan 1000 psm bagi kedua-dua baja. Purata kelebaran kerja optima adalah 1.8 dan 2.1 m seiring dengan 18 dan 19% nilai  $CU_G$  bagi urea butiran dan NPK butiran telah tercapai.

Bancuhan cecair kimia HC amine 48 dan NASA glyphosate masing-masing diuji pada 30 (rendah), 60 (sederhana) dan 90 l/ha (tinggi) kadar semburan pada empat kelajuan berbeza 2000, 3000, 4000 dan 5000 dengan tiga diameter piring berlainan 300, 400 dan 500 mm. Keputusan menunjukkan purata nilai VMD dari 342-102  $\mu\text{m}$  dan 344-108  $\mu\text{m}$  pada kelajuan 2000-5000 psm putaran piring dengan kadar aplikasi untuk NASA glyphosate dan HC amine 48 yang berbeza. Purata nilai NMD berubah dari 86 ke 208  $\mu\text{m}$  dan 82 ke 209  $\mu\text{m}$  masing-masing untuk NASA glyphosate dan HC amine 48.

Semua nilai ditentukan bagi pengesanan sifat semburan setiap cecair. Purata nilai  $CU_L$  sebagaimana VMD/NMD didapati dalam julat 1.25 ke 1.63 dan 1.22 ke 1.65 masing-masing untuk NASA glyphosate dan HC amine 48.

Perbandingan titisan semburan yang meliputi target antara Alat Aplikasi Bahan Kimia Putaran Piring Dwifungsi dan Alat Penyembur Galas Konvensional (CKS) menggunakan nozel kipas rata bertekanan hidraulik dari kajian-kajian bertulis menunjukkan 79% penghasilan titisan bersaiz 100-250  $\mu\text{m}$  berbanding Alatan Dwifungsi memberikan 80% titisan bersaiz 250-350  $\mu\text{m}$ . Ini menunjukkan Alatan Baru menghasilkan julat saiz titisan yang lebih kecil berbanding kaedah konvensional. Teknik penghasilan titisan yang bersaiz lebih besar dari cecair kimia boleh merubah kecekapan aplikasi dan pencemaran persekitaran. Keputusan dari ujian ladang mencadangkan purata keupayaan ladang berkesan meningkat kepada 0.89 ha/jam atau 7.12 ha/buruh-hari untuk 8 jam hari kerja, berbanding penggunaan penyembur galas bermotor dan lain-lain penyembur konvensional masing-masing sekadar 0.35 ha/jam (2.8 ha/buruh-hari) dan 0.20 ha/jam (1.6 ha/buruh-hari). Penggunaan alat ini menjimatkan kos operasi sebanyak RM7.7/ha (USD2.6/ha) dan RM12.5/ha (USD4.2/ha) berbanding penggunaan Alat Penyembur Galas Semburan Bermotor dan Alat Penyembur Galas Konvensional masing-masing.

## ACKNOWLEDGEMENTS

In the name of ALLAH, the most beneficent, the most merciful, all praises be to ALLAH the Lord of the world, also may the peace be upon the prophet Muhammad (SWA) and all his companions. I would start by thanking ALLAH (SWT) for providing strength and inspiration to reach this stage in my life. I would like to express the highest and deepest gratitude to Professor Ir. Dr. Desa B. Ahmad, M.I.E.M., P.Eng., P.C.M, the chairman of my supervisor committee for his invaluable encouragement, generous assistance, guidance and strong support throughout my study period. Thanks for everything Prof Desa. I am also indebted and grateful to Professor Dr. Shamsuddin B. Sulaiman, BEM, MIEM, MASME, Associate Professor Dr. Norhisam B. Mison, MIEEE, MIEM, IEEJ and Dr. Jamarei B. Othman, members of my supervisory committee for their constructive contributions. I really appreciate them serving in my supervisory committee.

I want to thank all the staff of the Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM) especially Mr Zainal Abidin and Mr Tajul whose valuable assistance have contributed in the successful completion of this study.

Thanks are also extended to the Bayero University, Kano (BUK) for providing me with the great opportunity to further my study. Also I want to extend sincere thanks to all the

staff of the Department of Agricultural Engineering, Faculty of Technology, BUK for all their support and encouraging messages.

I want to give the utmost appreciation to all my friends both at Malaysia and home (Nigeria) whose in one way or the other rendered assistance directly or indirectly and sharing of life experiences at various stages of my study but whose names are too numerous to mention. Thank you all for influencing my life positively.

Lastly, I want to thank my family; Maryam (wife), Al-Amin (son) and Fatima (daughter) who has been an inspiration during my study, supplying an endless amount of love, prayers, support and sacrifices. Thanks also to my parents, brothers and sisters for all their love, prayers and encouragement all the times in my life.

I certify that a Thesis Examination Committee has met on 28<sup>th</sup> September 2011 to conduct the final examination of Mohammed Shu'aibu Abubakar on his thesis entitled "Development of a New Concept Dual-Purpose Disc Agrochemical Applicator for Field Crops" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

**Mohd Amin bin Mohd Soom, PhD**

Professor  
Faculty of Engineering  
(Chairman)

**Wan Ishak Bin Wan Ismail, PhD**

Professor  
Faculty of Engineering  
(Internal Examiner)

**Dzolkhifli bin Omar, PhD**

Professor  
Faculty of Agriculture  
(Internal Examiner)

**K. P. Pandey, PhD**

Professor  
Department of Agricultural and Food Engineering  
I. I. T. Kharagpur, India  
(External Examiner)

---

**NORITA OMAR, PhD**

Associate Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

**Desa bin Ahmad, PhD, P.Eng**

Professor/Head, Department of Biological and Agricultural Engineering  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Shamsuddin bin Sulaiman, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Norhisam bin Misron, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Jamarei bin Othman, PhD**

Senior lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**HASANAH MOHD. GHAZALI, PhD**

Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:

## DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

---

**MOHAMMED SHU'AIBU ABUBAKAR**

Date:

## TABLE OF CONTENTS

	<b>Page</b>
<b>DEDICATION</b>	ii
<b>ABSTRACT</b>	<b>Error! Bookmark not defined.</b>
<b>ABSTRAK</b>	<b>Error! Bookmark not defined.</b>
<b>ACKNOWLEDGEMENTS</b>	x
<b>APPROVAL</b>	xii
<b>DECLARATION</b>	xiv
<b>LIST OF TABLES</b>	xix
<b>LIST OF FIGURES</b>	xxi
<b>LIST OF PLATES</b>	xxv
<b>LIST OF ABBREVIATIONS</b>	xxvii
<b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	<b>1</b>
1.1 General Introduction	1
1.2 Statement of Problem	5
1.3 Objective of the Study	6
1.4 Scope of the Study	7
1.5 Thesis Organization	7
<b>2 LITERATURE REVIEW</b>	<b>9</b>
2.1 Fertilizer Spreading in Agriculture	9
2.2 Centrifugal Fertilizer Spreaders' Particle Motion Models and Spread Patterns	10
2.3 Centrifugal Fertilizer Spreader Characteristics	18
2.4 Centrifugal Fertilizer Spreader Distribution Pattern Test Methods	21
2.5 Types of Granular Fertilizer Spreaders	26
2.5.1 Drop spreader	26
2.5.2 Centrifugal (rotary) spreader	27
2.5.3 Pendulum spreader	28
2.6 Pesticides Application in Agriculture	30
2.7 Fundamentals of Liquid Atomization	35



2.7.1	Liquid properties affecting the spray	35
2.7.1.1	Surface tension	35
2.7.1.2	Viscosity	36
2.7.1.3	Density	36
2.7.2	Types of Atomization Processes	36
2.7.2.1	Pressure (Airless) atomization	36
2.7.2.2	Centrifugal (rotary) atomization	37
2.7.2.3	Air (Airspray) atomization	38
2.7.2.4	Electrostatic atomization	39
2.7.2.5	Ultrasonic atomization	39
2.8	Reported Studies on Rotary atomizers	42
2.9	Centrifugal Force	50
2.10	Some Commercially Available Chemical Applicators	53
2.10.1	MDS 55, 65 and 85 models chemical applicator	53
2.10.2	Frontier SS10 series broadcast spreaders	54
2.10.3	FSP500, FSP700, FSP1000 series chemical spreaders	55
2.11	Summary of Literature	55
<b>3</b>	<b>MATERIALS AND METHODS</b>	<b>57</b>
3.1	Introduction	57
3.2	Design Consideration	57
3.2.1	Disc design	57
3.2.2	Granular fertilizer particle dynamics study on the rotary disc	58
3.2.3	Granular fertilizer particle dynamics study off the rotary disc	68
3.3	Characteristics of the Granular Chemical Disc	70
3.4	Characterization of the Granular Fertilizer	73
3.4.1	Particle shape	73
3.4.2	Particle moisture content	73
3.4.3	Particle density	74
3.4.4	Particle size distribution	74
3.4.5	Coefficient of friction	75
3.4.6	Coefficient of restitution	76
3.4.7	Aerodynamic resistance coefficient	77
3.5	Granular Chemical Fertilizer Material	77

3.6	Characteristics of the Liquid Chemical Disc	78
3.7	Liquid Spray Equation	79
3.8	Characteristics of Liquid Chemical	81
3.8.1	Density	82
3.8.2	Viscosity	82
3.8.3	Surface tension	82
3.9	Liquid Chemical Solution	83
3.10	Characterization of the Hopper	84
3.11	Fabrication of the Parts for the New Concept Dual Purpose Disc Agrochemical Applicator	85
3.11.1	Gear box	85
3.11.2	Rotary discs	88
3.11.3	Small Scale Dual-Purpose Rotary Disc Agrochemical Applicator	88
3.11.4	The Dual-Purpose Rotary Disc Chemical Applicator	90
3.12	Calibration of the Granular Chemical Applicator	93
3.13	Rotary Disc Granular Chemical Distribution Pattern/uniformity Experimental Test Procedure	96
3.14	Calibration of the Liquid Chemical Applicator	100
3.15	Rotary Disc Liquid Chemical Spray Droplet Size Collection Experimental Test Procedure	101
3.16	Determination of Rotary Disc Spray Droplet Size	103
3.17	Experimental Procedure	105
3.18	Machinery Field Evaluation	107
3.18.1	Theoretical field capacity, C	110
3.18.2	Effective field capacity, EFC	110
3.18.3	Field efficiency, FE	111
3.19	Economic Evaluation of the Chemical Applicator	112
3.20	Summary	115
<b>4</b>	<b>RESULTS AND DISCUSSION</b>	<b>117</b>
4.1	Introduction	117
4.2	Physical Properties of the Granular Fertilizer	117
4.3	Rotary Disc Granular Fertilizer Distribution Patterns	118
4.3.1	Urea granular fertilizer distribution patterns	119

4.3.2	NPK granular fertilizer distribution patterns	127
4.4	Data Analysis of Rotary Disc Granular Fertilizer Distribution Patterns	138
4.5	General Observation for Granular Fertilizer Distribution Patterns	144
4.6	Physical Properties of the Liquid Chemical	145
4.7	Rotary Disc Liquid Chemical Spray Droplet Size	146
4.7.1	NASA glyphosate liquid chemical spray droplet size	147
4.7.2	HC amine 48 liquid chemical spray droplet size	150
4.8	Data Analysis of Rotary Disc Liquid Chemical Spray Droplets Size	158
4.9	General Observation for Liquid Chemical Spray Droplets Size	163
4.10	Result from Large Scale Chemical Applicator	164
4.11	Field Performance of the Chemical Applicator on a Prime Mover	167
4.12	Economic Evaluation of the Dual-Purpose Chemical Applicator	169
4.13	Comparison of Reported Droplet Size Produced by Conventional Hydraulic Nozzle and that of the Dual-Purpose Rotary Disc Developed	172
4.14	Summary	175
<b>5</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	<b>177</b>
5.1	Conclusion	177
5.2	Contributions	179
5.3	Recommendations for Future Work	180
	<b>REFERENCES</b>	<b>181</b>
	<b>APPENDICES</b>	<b>190</b>
	<b>APPENDIX A</b>	<b>190</b>
	<b>Definitions</b>	<b>190</b>
	<b>APPENDIX B</b>	<b>193</b>
	<b>Calibration method</b>	<b>193</b>
	<b>APPENDIX C</b>	<b>195</b>
	<b>MATLAB Codes</b>	<b>195</b>
	<b>APPENDIX D</b>	<b>200</b>
	<b>Statistical Analysis</b>	<b>200</b>
	<b>BIODATA OF STUDENT</b>	<b>223</b>
	<b>LISTS OF PUBLICATIONS</b>	<b>226</b>