EVALUATION OF THE PERFORMANCE OF GRANULAR FERTILIZER BOOM SPRAYER THROUGH COMPUTATIONAL FLUID-PARTICLES-DYNAMID CFD SIMULATION AND SCALED-DOWN MODEL ANALYSIS

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ABSTRACT

Malaysian Agricultural Research and Development Institute (MARDI) had bought two Japanese made granular fertilizer boom sprayers to test it on Malaysia's Paddy field. In order to confirm the local feasibility of this fertilizer applicator, they had called UTHM researchers for proper experimental and numerical evaluations. A year of experimental assessments, the conclusion was supported with full range of numerical results and has a good agreement with MARDI's findings. In this evaluation, ANSYS CFD was used for the fluid-particles-structure simulation while the statistical and image processing were made via MATLAB software. The simulation results were verified with the results from an in-house scaled-down model which was fabricated with the ratio of 2:15. The simulation was carried out by manipulating the angles of the boom sprayer collecting plates, ranging from 32^o to 120^o. The length of the collecting plate, the distance of the blow head, the sizes of the fertilizer and the air velocity of the blower were also varied in order to establish the correlations between the parameters. The ambient pressure was kept at 1 atm. Even though we managed to find 60^o as the optimum collecting plate angle for most fertilizer sizes, there are two major factors that made it impossible to obtain good fertilizer distribution namely; the use of mixture of three different fertilizer (Nitrogen, Phosphorus and Potassium) sizes at once and the varying velocity profiles throughout the boom sprayer.

ABSTRAK

Institut Penyelidikan dan Kemajuan Pertanian Malaysia (MARDI) telah membeli mesin penyembur baja buatan Jepun untuk di uji pada sawah padi Malaysia. Bagi memastikan kebolehgunaan mesin ini, mereka telah memanggil penyelidik UTHM bagi mengkaji secara ujikaji dan simulasi. Selepas pengujian selama setahun, kesimpulan kajian tersebut telah disokong oleh pelbagai hasil berangka dan ujikaji simulasi ini jelas menyokong dapatan pihak MARDI. Kajian simulasi UTHM dijangka mampu menyokong penemuan ini melalui penilaian penuh terhadap parameter terbabit. Pungujian ini mengunakan perisian ANSYS CFD telah digunakan bagi tujuan analisis cecair-butiran-dinamik manakala analisis statistik dan pemprosesan imej telah menggunakan perisian MATLAB. Hasilnya disahkan melalui hasil ujikaji model berskala kecil iaitu menggunakan tetapan nisbah 2:15. Simulasi telah dibuat dengan mengubahsuai nilai sudut kepingan pengumpul pada penyembur baja pada julat 32^o ke 120^o. Panjang kepingan pengumpul, jarak antara kepala penyembur, saiz butiran baja dan kelajuan semburan udara juga diambil kira bagi mendapatkan hubungkait antara setiap pembolehubah. Tekanan udara sekeliling ditetapkan pada satu atm. Walaupun sudut kepingan pengumpul paling optima telah dipastikan pada 60^o, terdapat dua penyebab yang tidak membenarkan taburan baja yang baik dapat dicapai. Penyebab-penyebab itu ialah penggunaan campuran tiga jenis baja yang berbeza secara serentak (Nitrogen, Fosforus dan Kalium) dan perbezaan kelajuan semburan udara sepanjang penyembur jenis boom ini. Kajian susulan terhadap jenis-jenis penyembur baja berbeza dijangka mampu memberikan keputusan yang lebih baik.

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LIST OF SYMBOLS AND ABBREVIATION

Symbol

A	-	Area
A_1	-	Area of the actual boom pipe
A_2	-	Area of the scaled down boom pipe
D	-	Diameter
V	-	Air Velocity
V_{max}	-	Maximum Velocity
V_1	-	Velocity of the Actual boom sprayer
V_2	-	Velocity of the scaled down boom sprayer
D_n	-	Diameter of the Nitrogen
D_p	-	Diameter of the Phosphorus
D_k	-	Diameter of the Potassium
L	-	Length of the collecting plate
s	-	Distance of the blow head
r	-	radius
r_1	-	radius of the actual boom pipe
r_2	-	radius of the scaled down boom pipe
	-	dynamic viscosity
H	-	Height of the collecting plate
w	-	width
s	-	Distance between the boom section
Re	-	Reynolds Number
CFD	-	Computerized Fluid Daynamics

UTHM	-	University Tun Hussein Onn Malaysia
MARDI	-	Malaysian Agricultural Research and Development Institute
N	-	Nitrogen
P	-	Phosphorus
K	-	Potassium

CHAPTER 1

INTRODUCTION

1.1 Research Introduction

The main considerations of a researcher in carrying out any research is on its purposes, significances, contributions and novelties. Malaysian Agricultural Research and Development Institute (MARDI) had given a clear purpose to this research, which is to conduct a proper experimental and numerical evaluations on the Japanese made granular fertilizer boom sprayers. The outcome of the evaluation helps MARDI in decision making on the suitability of granular fertilizer boom sprayer to be used in Malaysia's paddy field. However, these findings are not just for the benefit of MARDI, but it also helps to develop Malaysia's agriculture as well. There is a clear difference between Japanese and local particles where we generally uses NPK fertilizer with different composition throughout the country. This condition acquires local farmers to mix Nitrogen (N), Phosphorus (P) and Potassium (K) fertilizer that have different sizes.

1.2 Background of Study

Agriculture plays a very important role in providing food to the world population and one of the common foods for Asian is rice. In Malaysia, the local paddy producing community is self–sustainable, covering up to 86% of local market demand while the remaining unfulfilled market demand is mitigated by importing rice from the neighboring rice producing countries such as Thailand, Indonesia, India and Cambodia. For the past few decades, productivity of paddy is one of the major concerns in agriculture fields. The causes that will affect the productivity of the rice had been taken into research in order to improve the productivity.

The improvements of growth of paddy cover a very wide areas such as the quality of the soil, the genetic of the plan, the quality of water, the surrounding environment, the use of pesticides to kill organisms that is harmful to the plant and the fertilizer which provides nutrition to the plan. One of the measures taken by MARDI is the quality of distribution of the fertilizer.

Fertilizer applicators are machines that are used to transfer the fertilizer into the field. The advantage of using the machine is high efficiency compared to human effort. It is quicker, has larger quantity of amount distribution and wider distribution compared to human effort. Fertilizer applicators which produced an even distribution will help each paddy plant to have enough nutrition and to avoid excessive usage. There are a few basic concept of distribution use by the applicators in the market such as gravity flow, rotating disc, pneumatic force and magnetic. For example, the applicators available in the market are; drop spreaders (gravity flow), boom sprayer (pneumatic force), centrifugal spreaders (rotating disk) and pendulum spreaders (magnetic).

There are many models which available in the markets. The differences will be in term of the method of distribution used, sizes, the power supplied and the design of the structure. Every fertilizer applicators in the market has its advantages and disadvantages. By seeing the potential of using fertilizer applicators in the paddy field, MARDI plans to use boom sprayer for their crop. Therefore, instead of comparing all concepts of fertilizer applicator in the market, MARDI called for an evaluation on boom sprayer only. Propose on the most suitable fertilizer applicators can be done based on journal findings. Currently there are two boom sprayers bought by MARDI to carry out their evaluation and MARDI require more evidence to support their conclusion of their findings. This evaluation on the boom sprayer that had brought which parameters have been optimized based on the Japan market is significant before these applicators are expected to be used nationwide.

The complement of the applicators toward the fertilizer distribution is a very important measurement for good and quality fertilizer applicators. The common use of fertilizer in Malaysia's paddy field is NPK fertilizer which is in granular form. Therefore, this evaluation was carried out based on the flow of NPK fertilizer inside the boom pipes of the boom sprayer. This type of fertilizer is for soil preparation prior to planting, in which the fertilizer is worked into the soil to provide nutrients to the plants and be established there. In Malaysia's paddy field, it is usually in granular form because of its low dissolvability which able to prolong the fertilizer in soil. As a result from using granular fertilizer, fertilization does not need to be carried out too often and it helps to save up fertilization cost. All these conditions need to be added into this evaluation.

1.3 Problem Statement

According to the statistic of Food and Agriculture Organization of the United Nations, in Malaysia, there are 6700 km^2 of paddy rice sown area. Therefore, applicators such as drop spreaders and centrifugal spreaders are not suitable for the large scale of field. The remaining applicators that are available for large-scaled field are boom sprayer, pendulum spreaders and dual-purpose disc rotatory disc applicator.

Among all these types of large scaled field fertilizer applicators, MARDI had called for the evaluation of the boom sprayer which they had bought. Proper experiment and numerical evaluation were expected to support the findings of MARDI.

The results of the distribution of the boom sprayer are affected by the flow of fertilizer inside the boom pipes. However, the distribution of granular fertilizer is usually more complicated than the distribution of liquid fertilizer. This is due to the flow of granular fertilizer was affected by the sizes of fertilizer.

The type of fertilizer taken into this evaluation is NPK. This type of fertilizer is available either in mixed form or singular form. Local practice generally prefers a mixed form rather than singular form which is more preferred in Japan. The advantage of using mixed form is the capability to manipulate the composition ratio of N, P and K according to the various type of soil to provide sufficient and suitable nutrient to the plant. N, P and K are actually consisting of different densities and sizes.

No doubt that boom sprayer has high efficiency for large scale usage. Boom sprayer is using pneumatic force which provided by the blower to push the fertilizer to flow throughout the boom pipe. It is gravity force that directs the fertilizer to fall to the ground. However, it is hard to control the air velocity to support the three types of fertilizer flowing at the same time. This is due to all the three types of fertilizer have various sizes.

Other than the physical properties of the fertilizer, the chemical properties of the fertilizer added the level of difficulties to achieve an even distribution. Mixing all three types of fertilizer will produce a chemical reaction that will dissolve the fertilizer into sticky liquid. The fertilizer ended up stuck in the hopper, metering and boom pipes. The boom pipes need to be replaced with new boom pipes from time to time. It is impractical for long term users and the maintenance cost is very high.

The study of the current designs of boom sprayer is highly needed, to open for more solution to solve the current problem. As MARDI found that the already brought boom sprayer gave bad distribution, it is expected that the mixed sizes of the fertilizer was the culprit of the situation. Proper research finding is needed to support the hypothesis.

1.4 Objectives

The objectives of this study are:

i. To evaluate the performance of existing granular fertilizer boom sprayer through computational fluid-particles-dynamic simulation analysis.
ii. To validate the results of the simulation on the performance of the existing granular fertilizer boom sprayer by in-house scaled-down experiment.
iii. To analyze the effect of angle, length and distance of the collecting plate on the performance of granular fertilizer boom sprayer.

1.5 Scope

Due to the huge size of boom sprayer, cost of experiments, and time consume, this research covered only fabrication of scaled-down boom sprayer. Scaled-down model was used throughout the experiment. For the simulation, the modeling only involved the parts that need to be evaluated such as the boom pipes and blow head for both scaled-down and full-scaled parameters. As for lab experiment, the addition parts involved are hopper, metering and the connection pipes.

There are three major sections in this work, namely to study the flow of particles (fertilizer) by using simulation from a commercial software ANSYS, the fabrication of scaled-down boom sprayer to analyze the particles movement from the inlet to the outlet of boom pipe and to recommend based on the overall results of evaluation.

Throughout the simulation process, the parameters manipulated are listed below;

i. Air velocity of the blower
ii. Diameters of fertilizer
iii. Densities of fertilizer
iv. The distances of the blow head
v. The lengths of the collecting plate
vi. The angles of collecting plate

Air velocity provided by the blower will affect the air velocity along the boom pipe. The flow of the particles is very much affected by the air flow in the boom pipes. For local practices, the diameter and the densities of particles (fertilizer) vary. Therefore, there is a need to manipulate both diameters and densities of the fertilizers to study the correlation of these parameters. The important parts in the boom sprayer which affect the flow of fertilizer will be the blow head and collecting plate. The distance of the blow head will affect the distribution coverage. Whereby, the amount of the fertilizer distribution will be affected by the lengths and the angles of the collecting plate.

The quality of the fertilizer distribution was determined by the quantitative and qualitative analysis. Qualitative analysis was made by observing the particles' tract while the quantitative analysis was based on the amount of fertilizer distributed to the ground. The amount was calculated via MATLAB. Graphs were produced from the statistical and image processing made via MATLAB software. The qualitative and quantitative analysis on images gave more evidence to the conclusion of the evaluation.

The experiment was made in a controlled environment where the experiment was carried out in the lab to eliminate the effect of wind, heat and the condition of landscape. In order to suit the lab-scaled, the boom sprayer was scaled-down to the ratios of 1:2 (half) from the original model. The reason for using this ratio was due to the availability of the material and the suitability of parameters of the model to be tested in the lab. The scaled-down model was used to verify and to validate the simulation results. The model was stagnant throughout the evaluation. Therefore, no movement, vibration and the drag force are involved.

This research was carried out due to MARDI called for experimental and numerical evaluation on boom sprayer only. The outcome of this evaluation are the optimum angle was identified, the results of the performance and the overall evaluation of the performance of the boom sprayer. The recommendation of this research involved the design on boom sprayer and the studies to be carried out in the future. As it is suggested that dual-purpose disc rotatory disc applicator can be considered as more suitable than boom sprayer based on the review on journals, future study on this applicator can be done by using the same evaluation tools in this research.

1.6 Significance of Study

The result of the evaluation was expected to help MARDI in decision making, whether boom sprayer is suitable to be used nationwide. The result of this research is not to replace boom sprayer. It is to evaluate the feasibility of the applicator based on the applications and the requirements set by MARDI. The same methodology used to evaluate the performance of the boom sprayer can be used to evaluate other granular fertilizer applicators in the future. This work introduces a better way of numerically evaluating granular fertilizer applicator by using simulation methodology rather than physically varying all the parameters involved in the applicator being analyzed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction on Literature Review

This chapter is divided into four major parts. The first part focuses the review on paddy industry (section 2.2 to 2.4). The second part focuses the review on the granular fertilizer applicators (section 2.5 to 2.6). The third and the forth parts of this chapter talk about the simulation (section 2.7 to section 2.11) and scaled-down model (section 2.12 to 2.14) respectively. The first part of the chapter shows the significance of this research in contributing to Malaysia's agriculture. It also provides information which is needed in this evaluation such as the properties of the fertilizer that are used for Malaysia's paddy and the conditions of the environment. The second part of the chapter describes the fertilizer applicators. From this part, we are able to identify the geometry structures and operation function of the fertilizer applicators that are available in the market. As a result, comparison was made between the boom sprayer and other fertilizer applicators based on the journals. The third part of the chapter is the information regarding the commercial software used to evaluate the boom sprayer. This part of chapter provides us the understanding of the reason that ANSYS was chosen and the guideline to use the software. The last part is the review on scaled-down model. The results of simulation are needed for verification and validation process through experiment. This part provides the understanding of using scaled-down model instead of full-scaled model and the methods to scale down the boom sprayer.

2.2 Demand of Paddy

In 2013 alone, paddy provides the bread and butter to 300,000 paddy farmers in Malaysia [1]. Land utilization for paddy production was at 674,928 hectares which was 76 percent in Peninsular Malaysia (515,657 ha) while Sarawak and Sabah accounted for 18 percent (118,919 ha) and 6 percent (40,352 ha) of the total hectare respectively [1]. If we look globally, India has one of the largest growing paddy fields in Asia and agriculture is one of the most important factors contributing to the economic growth of India [2]. Out of the 329 million hectares of India's geographical area, about 34.65 percent, 114 million hectares are under cultivation [2]. In Pakistan, researches were carried out to see the comparison of the yielding rate of double zero tillage, direct seeding of rice, brown manuring, transplanting on beds and conventional transplanting [3]. The highest number of productive tillers/unit even (231.7) were noted in direct seeding followed by double zero tillage (219), bed planting (206.7) and conventional planting (200.2) respectively [3]. Therefore, growing paddy is not just the major concern of Malaysia but in Asia as well. In order to increase the self-sufficiency level (SSL) without decreasing the importation of rice, the production of paddy must be increased to meet all the needs [4].

2.3 Paddy and Rice Industrial Strategies in Malaysia

In order to achieve full self-sufficiency, strategies as shown in Table 2.1 had been implemented by Malaysian government to ensure that the production of rice is able to reach 2 million metric tons by 2020 with total parcel areas of 416,000 hectares [4]. In addition, four new granaries in Rompin and Pekan, Pahang; Batang Lupar, Sarawak; and Kota Belud, Sabah will be developed.

Since 2005, MARDI has been carrying out research in aerobic rice farming. The benefit of having aerobic rice is that it is high yielding plants which only take 90 days to ripe and 50 percent lower water usage compared to normal rice [5]. In order to fully utilize the landscape of Malaysia especially hilly places in Sarawak and Sabah, hilly paddy has also been developed by MARDI to increase the productivity of the paddy [6]. Hilly paddy does not require any fertilizer to grow but it take around 150 days to ripe [6]. MARDI also produced a breed of rice known as MR220 CL1 and

CL2 which able to withstand diseases and pest like “weedy rice” [7]. They are resistant to the herbicide that will enable it to withstand the herbicide that is used to poison the weedy rice.

Table 2.1: Strategies implemented by Malaysian government to ensure the production of rice. [8]

Strategies	**Implementation**	**Result**
i) consolidating small farms	a. Consolidate paddy fields averaging 2.2 hectares into estates of more than 100 hectares to be managed by PPKs or private companies. b. Agriculture NKEA, special incentives of RM2,000 per hectare per season for up to five seasons will provides for farmers who join the group farming initiative c. profit sharing and employment opportunity given to the farmers	Expected to raise the paddy yield from 5 metric tonnes per hectare to 8 metric tonnes per hectare and increase the income of farmers by 5% by 2020.
ii) providing adequate irrigation and drainage infrastructure	a. High density polyethylene pipes will be used as an alternative to reduce construction and maintenance costs of infrastructure in new granaries. b. Water management groups or Kumpulan Pengguna Air set up among the farmers will be revived to manage water resources and encourage voluntary maintenance of infrastructure in their respective areas. c. Radio telemetry and Supervisory Control and Data Acquisition as practised in the Muda Agricultural Development Authority (MADA) area will be expanded to other granaries for effective management and monitoring of water distribution.	expected to increase crop intensity from an average of 188% (1.8 times per year) in 2014 to 200% (two times per year) in 2020.
iii) Enhancing Knowledge and Skills of Farmers	a. Lead farmers will be trained by agencies such as MADA and NATC who will in turn train other farmers in the designated area. b. Training programs on the use of fertilizer on a scheduled basis, water management, pest and disease management and managing impact of climate change	Enhance knowledge of farmers

Table 2.1 (continued): Strategies implemented by Malaysia government to ensure that the production of rice [8].

Strategies	**Implementation**	**Result**
iv) Targeting on Performance-Driven Assistance	a. Various input assistance such as fertilizer and pesticide for paddy cultivation will be given to farmers according to soil conditions, types of pests and weeds as compared to the standard assistance provided irrespective of the needs of farmers. b. MARDI will assist MADA, Kemubu Agricultural Development Authority (KADA) and Integrated Agricultural Development Areas (IADAs) to determine the suitability and requirement of inputs for maximum productivity gains. c. Input assistance will be extended to farmers in Sabah and Sarawak to promote sustainable hill rice production in permanent areas and discourage shifting cultivation practices.	Increasing production.
v) Introducing new high yielding varieties,	a. New certified paddy varieties such as MR253, MR263 and MR269 which offer better yield and resistance to disease will be widely promoted, particularly in disease prone areas. b. Planting of aerobic rice, a paddy variant that is heat resistant and requires less water will be promoted in areas where single season planting is carried out due to poor water supply.	Aerobic rice enables three planting cycles a year and is expected to increase the income of farmers.
vi) Improving Post-Harvest Handling Chain	a. Improving the post-harvest handling chain including harvesting, drying, storage, transportation and milling activities. b. Research will focus on improving the efficiency of harvesting machines, drying and storage facilities as well as milling technology. c. More drying and storage facilities will be built to help farmers store their paddy before transporting to rice mills.	Reducing post-harvest loss from an average rate of 30% to 15% will increase the overall production of rice thus raising the income of farmers.
vii) Gazetting granaries and non-granaries as permanent rice production areas	Retain land for paddy cultivation on a permanent basis.	Ensure sufficient production of rice.

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