DESIGN OF A PNEUMATIC GRANULAR APPLICATOR FOR PADDY FIELD

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ABSTRACT

Most operations related to the application of granular agrochemicals in korea are manual and labour consumming. As a multipurpose granular applicator, a pneumatic granular applicator that can be attached to conventional ride-on machines for paddy field was designed in this study. Experiments and simulations were carried out for determining the design factors with one fertilizer(DongBu 21-17-17) and one pesticide(SamKong Ivi). The maximum terminal velocity of granular chemicals was estimated as 14.2m/s. A better distribution pattern was obtained at the diffuser having only deflectors without dividing guides. The diffuser spacing 1.0m for the fertilizer and the diffuser spacing 0.8m for the pesticide at the boom heights over 0.80m were acceptable for the uniform distribution. In the case that the forward speed of ride-on machines was 0.7m/s, the groove opening and the roller speed of the selected metering device were 13mm-15mm at 2 rps for the fertilizer, and 9mm-11mm at 0.25rps for the pesticide. This study suggested a method of developing a pneumatic applicator for granular agrochemicals.

Key Words : Pneumatic granular applicator, Terminal velocity, Diffuser, Distribution pattern and Uniformity.

INTRODUCTION

At present, mechanization ratios on various farm operations are considerably high in korea. However, most operations related to the application of agrochemicals are manual and labour-consuming. In particular, applying granular agrochemicals in paddy field almost depends on human labor.

The demand for granular agrochemicals is increasing because the granules cause less drift, resulting in less damage to animals and human beings. Some applicators for granular agrochemicals have been supplied in domestic market but they have many operational restrictions. Each applicator is designed to apply only a specific type of granular chemical. In growing season, the applicators can not be used in paddy field because rice plants are very dense and the ground is too wet and muddy for operators to work on in fields. On taking consideration of production and consuming quantity for granular agrochemicals, it is a pressing demand to develop a comprehensive granular applicator which can apply various types of granular chemicals in paddy field during growing season.

As a multipurpose granular applicator, a pneumatic granular applicator that can be attached to conventional ride-on machines for paddy field, such as a rice-transplanter, was suggested in this study. General concepts involved in designing the applicator were a wide application width using a boom, an uniform distribution using diffusers, a constant discharge of granules using grooved metering devices, a pneumatic conveying and distribution of granular agrochemicals, and a simple and light mechanism. Based upon the concepts, a pneumatic granular applicator was developed in the study.

DESIGN CONSIDERATIONS

The pneumatic granular applicator designed in the study consisted of a blower, a hopper, a metering device, an air-granule mixing unit, a diffuser, a power line driving the metering device, and a boom. Specific factors associated with developing the applicator were the air velocity, the speed of grooved roller, the groove opening in the metering device, the shape and size of diffuser, the spacing between diffusers on a boom and the boom height for uniform distribution.

Blower selection

A criterion in selecting a blower was a minimum air quantity necessary for conveying and spreading granular agrochemicals. The air quantity was calculated by using Eq. (1).

$$\text{Air quantity} = \text{cross sectional area} \times \text{terminal velocity} \times \text{number of conveying pipes} \times \text{safety factor} \quad (1)$$

In general, an air quantity relates to a terminal velocity that can be calculated by using a drag coefficient and a Reynold's number(Eisner, 1930). The terminal velocities of granular agrochemicals were obtained by using Eq. (2) with their nominal densities and diameters.(Goering et al., 1972; Pitt et al., 1982). Solving Eq. (2) required an iterative method because the equation analytically suggested no specific solutions.

$$\ddot{z} = g - C \cdot \dot{z} \cdot \sqrt{\dot{h}^2 + \dot{z}^2} \qquad (2)$$

where h = horizontal direction, m
z = vertical direction (positive downward), m
C = $0.5 \cdot C_D \cdot \rho_a \cdot A_p / M$
C_D = Drag coefficient
g = acceleration of gravity, m/s^2
A_p = projected frontal area of particle, m^2
M = mass of particle, kg
ρ_a = mass density, kg/m^3

Diffuser selection and distribution uniformity

Factors affecting the distribution uniformity of granular agrochemicals were the air velocity, the diffuser spacing(overlapping ratio), the application height, and the shape and size of diffuser. The coefficient of variation(CV) is an index to represent the distribution uniformity. A type of diffuser to be installed on a boom was determined through obtaining the distribution patterns for each type of diffuser, and simulating the CV for the type at various diffuser spacings and boom heights.

Roller axle speed and groove opening

The required quantity of agrochemical in a field varies according to its type but, in general, is about 4kg/10a for pesticides and 40kg/10a for fertilizers. When the speed of ride-on machine and the effective distribution width of applicator are determined in a paddy field, the discharge quantity per grooved roller metering device per unit time is calculated by dividing the required quantity by the application time and the number of metering devices.

In a grooved roller metering device, grooves are continuously filled with granules and the granules are discharged into an air-granule mixing unit by gravity along with the rotation of roller. The discharge rate is determined by adjusting the groove opening. In theory, the discharge rate should be proportional to the roller speed and the groove opening but it would not show the linearity due to incomplete filling of groove cavities at high roller speeds. In this study, a wider groove opening at a slow roller speed was recommended as a better combination for the constant discharge of granules.

EXPERIMENTAL MATERIALS AND METHODS

There are various types of granular fertilizers and pesticides in korea but, as experimental materials, one fertilizer(DongBu 21-17-17) and one pesticide(SamKong Ivi) were used in this study.

Discharge characteristics of grooved roller

A set of metering device was installed on an experimental frame to obtain the discharge characteristic of grooved roller. The roller was driven by a VS-motor through a chain and a speed reducer. Roller speeds in this experiment were 0.25, 0.5, 1, 1.5, 2, 2.5 and 3 rps for the pesticide, and 0.5, 1, 1.5, 2, 2.5, 3, 3.5 rps for the fertilizer, respectively. The experimental levels of groove opening were increased by a 2mm step in the range of 3mm-19mm.

Distribution patterns of diffusers

In the study, 5 models of diffusers at 3 types were selected for the experiment(Fig.1). The selection was random based on reviewing previous studies. In particular, the diffuser models (b), (c) and (d) in the figure were the same type but their spreading angles were 60°, 80° and 100°, respectively. These models were devised to investigate the angle effect of diffuser. The type (e) had no guide and plate with only 3 deflectors as a simplest shape.

A blower(NF411, JungAng Co.) was used for the experiment. The granules sprayed from the diffuser were collected in PVC collectors which were made of PVC pipes in 7cm diameter. The collectors were equally spaced 6.5cm in 3m×2m area, and the dividers with 20cm height were inter-located between the collectors to avoid a bounding effect of granules.

Air velocities were 14m/s, 31m/s for the fertilizer, and 14m/s, 27m/s for the pesticide, respectively. The height of diffuser for the experiment was fixed at 60cm, 80cm and 100cm from the collectors. The results for the distribution patterns of the selected diffusers were used for simulating the distribution uniformity at various diffuser spacings and boom heights.

RESULTS AND DISCUSSION

Terminal velocity and air quantity

The estimated densities for granular agrochemicals were in the range of 1759~2871kg/m^3. The maximum diameters of granular agrochemicals were in the range of 5~10mm for the fertilizer, and of 1.2~2.0mm for the pesticide, respectively.

Table 1 shows the physical properties and the terminal velocities of granular agrochemicals. The terminal velocities in the table were calculated by using the maximum diameter for design safety. The results were the estimated values when the granules were considered as an equivalent sphere. The maximum terminal velocity of granular agrochemicals was 14.2m/s.

The discharge rate for the roller speed and the groove opening

Fig. 2 shows the relationship between the roller speed and the discharge rate. The discharge rate logarithmically increased with increasing the roller speed and decreased over the roller speed 3.0 rps due to incomplete filling of the granules. However, the discharge rate proportionally increased as groove opening increased(Fig. 3). The selected metering device had the wide range of discharge rate which would be a necessary characteristic in order to apply the required amount of granular agrochemicals at various forward speeds of applicator or effective application widths in fields.

Diffuser selection and application condition

Fig. 4 shows the distribution patterns for the type (c), (d) and (e). The experimental results for distribution patterns showed that the patterns for the fertilizer having larger granules were more uniform than those for the selected pesticide. As shown in the figure, a better pattern was obtained at the type (e) having only deflectors without dividing guides.

Based on the distribution patterns, the simulation was performed to obtain the optimum combinations of diffuser spacing, boom height and air velocity for an acceptable uniform distribution(Fig. 5, 6). The CV 15% was used as a critical standard for distribution uniformity. Table 2 shows the combinations of diffuser spacing, boom height and air velocity resulting in the CVs less than 15%. As shown in the table, the diffuser spacing of 1m for the fertilizer and the diffuser spacing 0.8m for the pesticide at the boom heights over 0.8m were acceptable.

In general, the forward speed of ride-on machines for paddy field is in the range of 0.5-0.7m/s. In this study, the maximum speed 0.7m/s was used for simulation. To apply the required amount of granular chemicals, groove opening and roller speed were 13mm-15mm at 2 rps for the fertilizer, and 9mm-11mm at 0.25rps for the pesticide, respectively.

CONCLUSIONS

As a multipurpose granular applicator, a pneumatic granular applicator that can be attached to conventional ride-on machines for paddy field was designed in this study. Specific factors necessary for developing the applicator were the air velocity, the speed of grooved roller, the groove opening in the metering device, the shape and size of diffuser, the spacing between diffusers on a boom and the boom height for uniform distribution. Experiments and simulations were carried out for determining the design factors with one fertilizer(DongBu 21-17-17) and one pesticide(SamKong Ivi) in this study.

The maximum terminal velocity of granular agrochemicals was estimated as 14.2m/s. The discharge rate proportionally increased as groove opening increased. A better distribution pattern was obtained at the type of diffuser having only deflectors without dividing guides. The diffuser spacing of 1m for the fertilizer and the diffuser spacing of 0.8m for the pesticide at the boom height over 0.8m were acceptable for uniform application. In the case that the forward speed of ride-on machines was 0.7m/s, the groove opening and the roller speed of the selected metering device were 13mm-15mm at 2 rps for the fertilizer, and 9mm-11mm at 0.25rps for the pesticide. This study suggested a method of developing a pneumatic applicator for granular agrochemicals.

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Table-1. Material properties and calculated terminal velocities for agrochemical

	Brand	Maximum Diameter(mm)	Estimated density(kg/m^3)	Terminal velocity(m/s)
Fertilizer	NamHae,21-17-17	5.00	1870	14.1788
	DongBu,21-17-17	5.00	1780	13.8272
	Namhae,17-21-17	5.00	1870	14.1788
	Namhae,Urea	5.00	1530	12.8013
	GyungKi,Urea	5.00	1580	13.0128
Pesticide	Pododaejang	2.00	2240	9.4196
	Mannyang	1.19	1920	6.3065
	Whochiwang	1.19	1990	6.4324
	Pumhana	2.00	1967	8.7963
	Handle	2.00	1913	8.6680
	Solnet	2.00	2729	10.4484
	Nonanmae	2.00	2202	9.3351
	Ivi	2.00	1759	8.2921
	Stomp	1.19	2101	6.6277
	Orija	2.00	2871	10.7297

Table-2. Combinations of application factors in CV≤15(%) for tested granular agrochemicals(~Diffuser spacings(m), application heights(m)~ at each air velocity)

Diffuser type \ Air velocity		12~16m/s	26~28m/s	30~32m/s
Pesticide	B		~0.26, 0.60~	
	C	~0.26, 0.60~	~0.26, 0.60~	
	D	~0.26, 0.60~	~0.26, 0.60~	
	E	~0.52, 0.60~	~0.52, 0.60~ ~0.78, 0.80~	
Fertilizer	B	~0.26, 0.60~		~0.26, 0.60~
	C	~0.39, 0.60~ ~0.46, 0.80~ ~0.52, 1.00~		~0.52, 0.80~
	D	~0.46, 0.60~ ~0.52, 0.80~ ~0.65, 1.00~		~0.65, 0.80~
	E	~0.65, 0.80~		~1.00, 0.80~ ~1.17, 1.00~

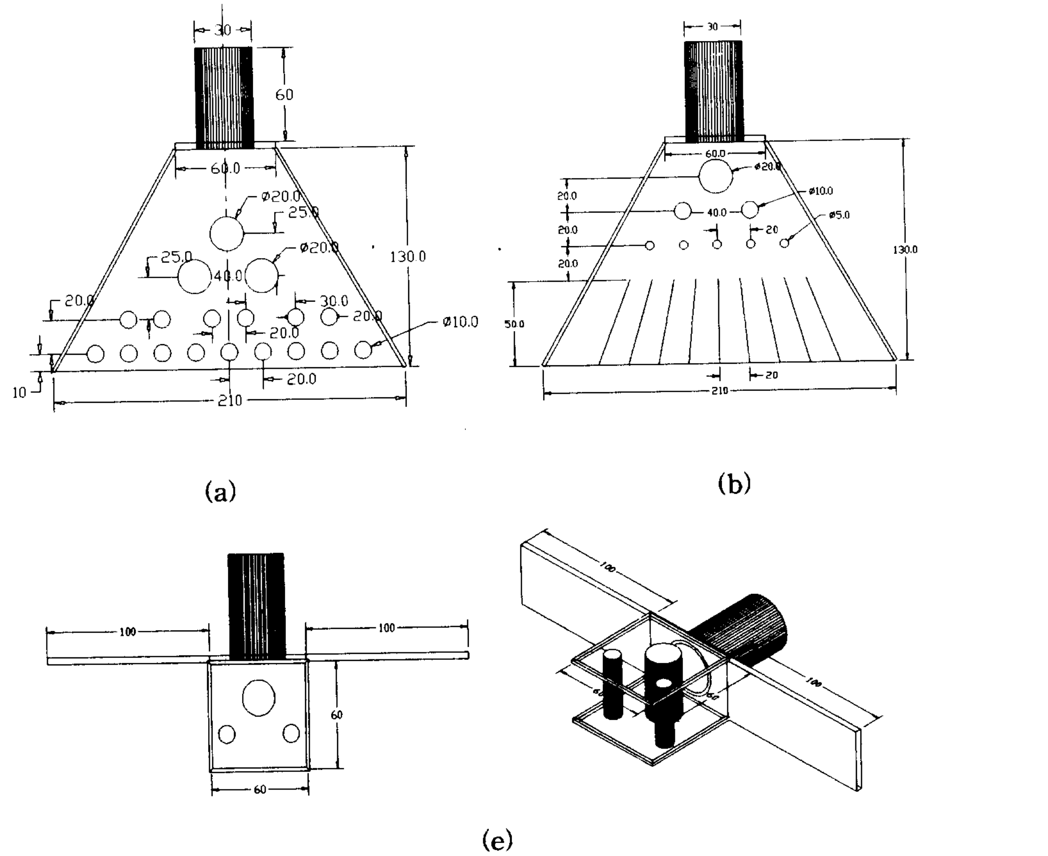

Fig. 1. Diffuser types used in the experiment(diffusers c, d are the same type but differ in spreading angle).

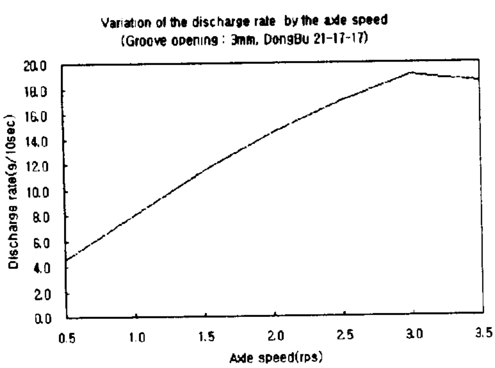

Fig. 2. An example showing the increasing of discharge rates.

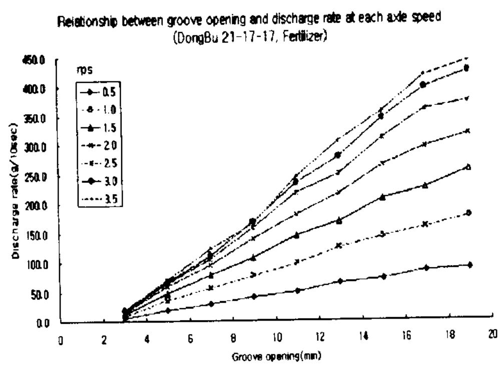

Fig. 3. Relationship between groove opening and discharge rate(DongBu 21-17-17).

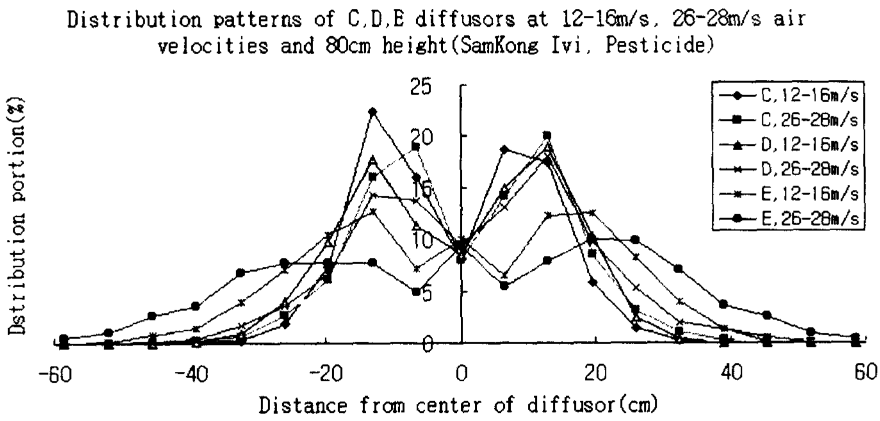

Fig. 4. An example showing distribution patterns of diffuser c, d, and e types.

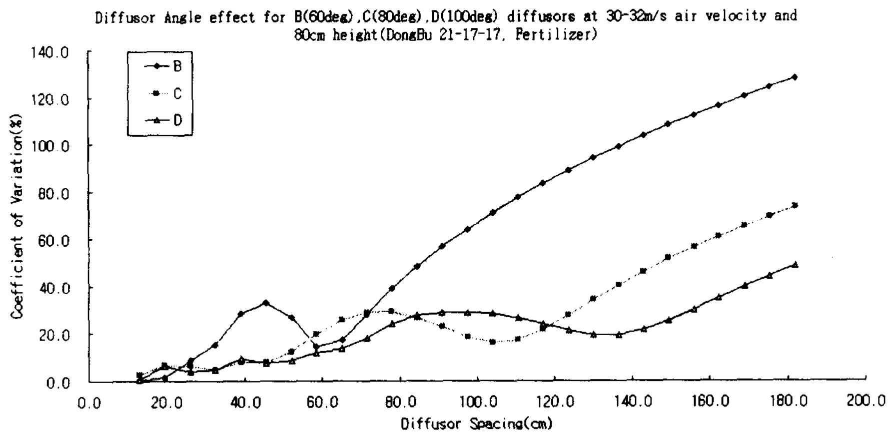

Fig. 5. Angle effect on CV variations by diffuser spacing.

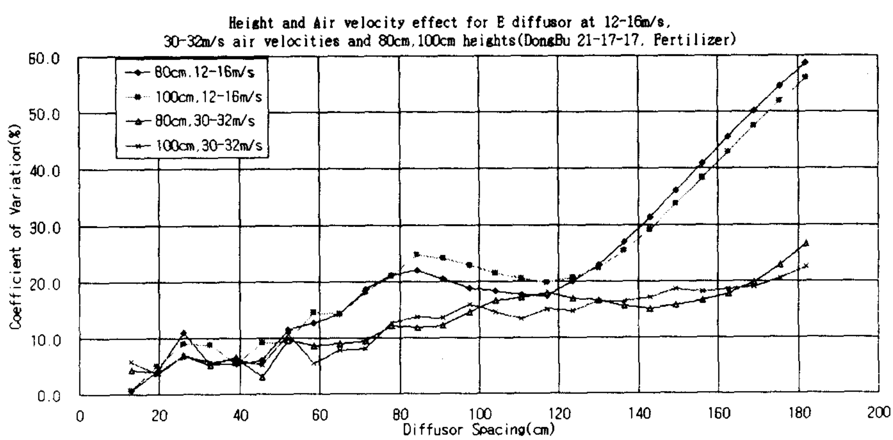

Fig. 6. Height and air velocity effect for the diffuser type of e.