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AN ELECTRICAL ROTARY CAGE ATOMIZER FABRICATED FOR SPRAYING ORCHARD

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Abstract

The environmental contamination due to off-target deposition of pesticide droplets can be minimized by using optimum design and operating parameters of sprayers. The fabricated electric rotary cage atomizer manufactured from the following component, rugged stainless steel welded frame with protective air intake grate, the center axial fane, high strength fiberglass protective and DC electric motor. The motor rotating speed was 3500 rpm. The liquid distribution system consisted of a metal liquid feed channel with holes leading to a series of grooves on the insides of the vanes between the slots. The open-ended design allowed the cage to act as a small centrifugal fan. This paper describes a collaborative theoretical and experimental research effort to investigate the performance of developed electric rotary cage atomizer utilized in agricultural field specially to spray orchards. A three-dimensional computational fluid dynamics (CFD) model was developed and used to evaluate concepts of rotary cage atomizer sprayer setup to orchard spraying to reduce drift without a decrease in biological efficacy. The result indicated that the maximum power requirement for single and two rotary cage spryer atomizers were 29.76 W and 55.2 W at rotational speed 3,500 rpm respectively. The maximum air velocity was recorded 5.3 ms-1 at out let distance 20 cm and rotational speed 3,500 rpm. The values of droplet size D0.5 were 251.72 at operating condition 0.4 L min^{-1}, 1,500 rpm and 0.5 ms^{-1} air velocity compared with droplet size D0.5 80.23 at operating condition 1.4 L min^{-1}, 3,500 rpm and 5.3 ms^{-1} air velocity. The increasing of the air velocity (U), rotational speed (Ω) and liquid flow rate tends to decrease the droplet size D0.25, D0.5, and D0.75. The values of droplet size D0.5 were 251.72 at operating condition 0.4 L min^{-1}, 1,500 rpm and 0.5 ms^{-1} air velocity compared with droplet size D0.5 80.23 at operating condition 1.4 L min^{-1}, 3,500 rpm and 5.3 ms^{-1} air velocity.

Key words: *electric rotary cage, atomization, sprayer*

INTRODUCTION

Egypt Washington navel orange (*Citrus sinensis* L. Osbeck) is one of the most important species in the genus citrus and ranked first among the species of citrus. It occupies about 35 % of the total cultivated area of citrus, since its acreage reached about 79,426 ha with total production of 1,663,284 tons per year according to the last census, issued by Ministry of Agriculture, Egypt (2015) [1]. Egypt is one of the world's leading orange producers and exporters. The orchard row middles typically require mowing several times per year to provide access through the planting for workers and equipment, to reduce vole habitat, and to reduce moisture in tree canopies. Air-assisted sprayers use air jets to carry pesticide droplets to the target position, to displace the air inside the crop canopy and to assist a uniform deposition of the pesticide droplets on the targeted surface. Preliminary data in demo trials suggest that this setup reduces drift without decreasing the biological efficacy. The use of modelling is an alternative to the expensive and difficult experimental and field measurements and provided a model for the droplet impact and deposition on crops [10]. In addition, [11] found that a spray of almost uniform droplet size is formed when liquid is fed onto the center of a spinning disk, and centrifuged off the edge in droplet form. They reported that the mean droplet size can be correlated with operating parameters by the following equation:

$$d_{\mathrm{vmd}} = K_1 \left(\frac{\sigma}{\rho D \omega^2} \right)^{0.5}$$

Fraser and Eisenklam (1956) [2] reported that the mean diameter of spray droplets can be correlated with operating variables for rotary disk atomizers as:

$$d_m = 3.8 \left(\frac{\sigma}{\rho D \omega^2} \right)^{0.5}$$

Reley (1959) [5] used flat spinning disks with different diameters, rotational speeds, and flow rates to obtain uniform droplet sizes. He correlated Sauter mean diameter (d32) with operating variables as follows:

$$d_{32} = K\sigma^{1.35} Q^{0.19} \rho^{-0.06} \omega^{-1.41} D^{-0.66} \mu^{-1.48}$$

Kayano and Kamiya (1978) [4] developed a correlation for the mean droplet sizes produced by a rotating disk as:

$$d_{32} = 2.0\, D^{-0.69}\, \omega^{-0.79}\, Q^{0.32}\, \mu^{0.65}\, \sigma^{0.26}\, \rho^{-0.29}$$

The objectives of the current research were manufactured and evaluated an electric rotary cage atomizer sprayer for orchards tree. As well as using the theoretical model to predicate the droplet size from the fabricated rotary cage atomizer. Also, the goal of this investigation is to produce a validated theoretical model capable making timely predictions of atomizer performance.

MATERIALS AND METHODS

The current research conducted in Agricultural Engineering dept., faculty of agriculture, Kafrelsheikh University, Egypt during session 2018/2017. The rotary cage atomizer or controlled droplet applicator (CDA) has been used for years in aerial application but is a relative new device for ground application [6]**.** The rotary cage atomizer nozzles form the spray by using centrifugal force at a rotating disk of wire cage rather than forcing the liquid through a nozzle orifice. The fabricated electric rotary cage atomizer manufactured from the following component, rugged stainless steel welded frame with protective air intake grate, the center axial fane, high strength fiberglass protective and DC electric motor. The motor rotating speed was 3,500 rpm. The liquid distribution system consisted of a metal liquid feed channel with holes leading to a series of grooves on the insides of the vanes between the slots. The open-ended design allowed the cage to act as a small centrifugal fan. Figure 1 indicates the construction of developed an electric rotary cage atomizer unit. The rotary cage atomizer was operated from 1,500 rpm to 3,500 rpm by increasing of 500 rpm. The flow-rate was increased from 0.4 l/min to 1.2 l/min by steps of 0.2 l/min corresponding to water acceptable volume rate 100 l/ha at forward speed ≈ 5 km/h and working width in orange trees when using two rotary cage atomizers in the completely prototype sprayer as shown in Figure 2. The air velocity was measured at different out let distance from rotary cage atomizer without liquid. The anemometer was fixed at 0.18 m from the center of rotary cage atomizer and at different out let distance (from 0.2 m to 1.2 m by increasing of 0.2 m). All measuring data were collected and analyzed.

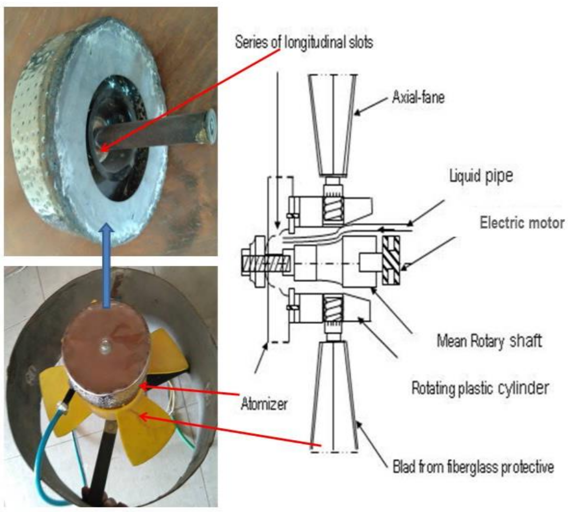

Fig. 1. The diagram of fabricated an electric rotary cage atomizer
Source: Authors' own illustration.

Power source of the development electric rotary cage atomizer

The dry battery is very sensitive in the charging and needs a special charger to control the charging. The charger delivers 10 A to the battery. When a dry battery is discharged 80% and only 20% capacity is left in the battery, the overall lifetime of the battery (if not recharged at this point) is reduced a lot. This means that the battery will last longer if it is recharged with 20% capacity left. The battery can get destroyed if the battery is more than 90% discharged. This means that the battery only has to charge 80% of the 70 Ah. The chargeable time of this battery could be calculated as follow: 70Ah·0.8/10Ah/hour = 5.6 hours. The battery chargeable time 5.6 hours presupposes that the battery is 100% efficient at absorbing the charge. The battery is charged with a charge controller and the reduction of power battery (BPR) has to receive as follow:

BPR = (1-E2*I2 /E1*I1**)** as mentioned [7]

where:

BRP is the reduction power rate of battery,

E_1 is the voltage at start operation and

E_2 is the voltage after 15 min, 30 min, 45 min and one hour operation.

The I_1 and I_2 value is the electric current with ampere measured at start and during the operating time respectively.

The inverter model Deka 1,500 converted the 0.12 kW DC power to 1.32 kW AC power to operate the Turbo QB60 hydraulic pump with power 0.37 kW. As well as the elapsed time was recorded at 80 % from the battery efficiency to start the rechargeable. The multi-meter MS 345 was used to measure the power consumption directly from the inverter Deka1500 [7], [8].

Test procedure and laboratory test

The electric power from the tractors' dry battery was evaluated to operate the weeder DC motor.

The battery remaining rated and capacity was measured by using the Tektronix Oscilloscope Model TPS 2024.

State of Charge (SOC) is defined as the remaining capacity of a battery and it is affected by its operating conditions such as load current and temperature. SOC is a critical condition parameter for battery management. Accurate gauging of SOC is very challenging, but the key to the healthy and safe operation of batteries. The SOC determined by the following formula:

SOC= (Remaining capacity/Rated capacity) according to [9] , [12].

The testes for operation the electric rotary cage atomizer depending up on the dray battery that charged by the tractor generator was 5 minutes for every trail.

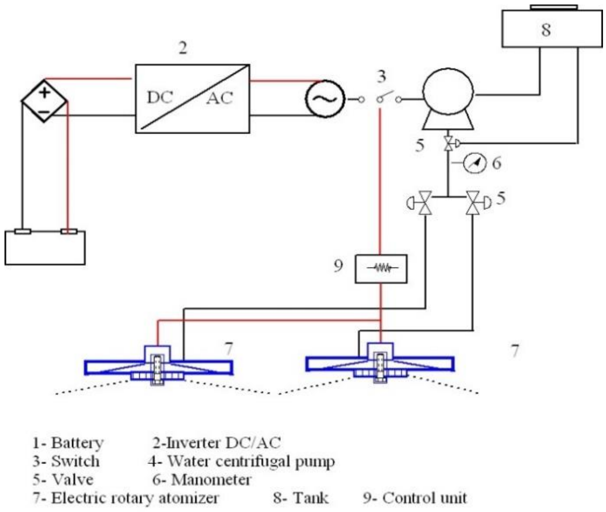

Fig. 2. Two rotary cage atomizers in the completely prototype sprayer with electricity circuit and water line.
Source: Authors' own illustration.

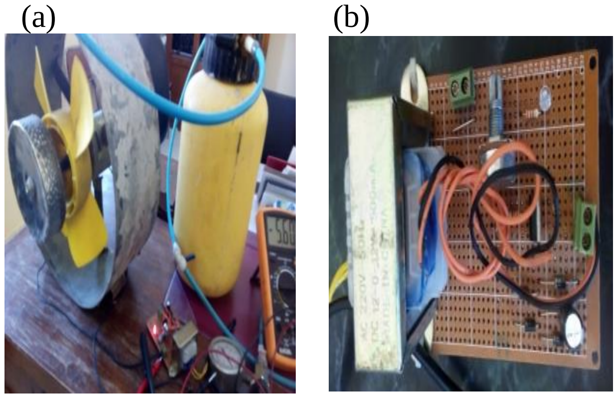

Fig. 3. The rotary cage atomizer test (a) in laboratory and electricity circuit control unit for rotational speed and power requirement (b).
Source: Authors' own illustration.

Fan outlet velocity

The measurement of this air velocity at the fan outlet was done in a laboratory room of 20 m long and 8 m wide. Based on measured values in the experimental room, an air temperature of 23 ◦C and relative humidity of

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74% were used. A steady state simulation with a moving coordinate system (the speed equal to the ground speed of the tractor) was implemented.

Spray atomization model

The theoretical model to predicate the droplet size from the fabricated rotary cage atomizer was developed correlations for mean droplet size produced by air shear rotary cage atomizers are studied by [3]**.**The following equation cited by Hewilt was used to predict the droplet size under all rotational speed of the developed electric rotary cage atomizer and their operating conditions:

$$D_{V0.25} = 28.122\left(\frac{U}{U_{max}}\right)^{-0.331}\left(\frac{Q}{Q_{max}}\right)^{0.103}\left(\frac{\Omega}{\Omega_{max}}\right)^{-0.992}$$

$$D_{V0.5} = 50.258\left(\frac{U}{U_{max}}\right)^{-0.327}\left(\frac{Q}{Q_{max}}\right)^{0.056}\left(\frac{\Omega}{\Omega_{max}}\right)^{-0.714}$$

$$D_{V0.75} = 67.129\left(\frac{U}{U_{max}}\right)^{-0.359}\left(\frac{Q}{Q_{max}}\right)^{0.068}\left(\frac{\Omega}{\Omega_{max}}\right)^{-0.706}$$

where:
U_{max} = 6 m s^{-1}, Q_{max} = 5 L min^{-1}, and Ω max = 3,500 rpm, were submit in the above equation to estimate the droplet size.
The R^2 = 0.964, 0.962, and 0.978, respectively. The arithmetic diameters of the droplets of the droplets were computed directly from the raw measurements using MATLAB (Mathworks, Natick, MA).

RESULTS AND DISCUSSIONS

The result of the measuring laboratory tests indicated that the power requirement for developed single and two rotary cage atomizers was illustrated in Figure 4. The maximum power requirement for single and two rotary cage spryer atomizers were 29.76 W and 55.2 W at rotational speed 3,500 rpm respectively. Also, increasing the rotational speed tends to increase the power requirements for developed electric rotary cage atomizer.

Figure 5 indicated that the relation between the out let distance and produced air velocity from developed electric rotary cage atomizer under different rotational speed. The increasing of out let distance gave the low air velocity under all test rotational speed conditions. The maximum air velocity was recorded 5.3 ms^{-1} at out let distance 20 cm and rotational speed 3,500 rpm. As well as the mean value of air velocity was 4.3 ms^{-1} at out let distance 60 cm. This value is the indicator of the velocity droplet size produced from the developed electric rotary cage atomizer into the target or orchards. It could be able to operate the electric rotary cage atomizer to produce different droplet velocities. This result may be utilized for different orchards to spray. As well as it is essay to control the droplets and air velocities by changing the power sources of the rotary cage atomizer using the manufactured control unit. Also, their maintenance will be able and very chip compared with hydraulic rotary cage atomizer.

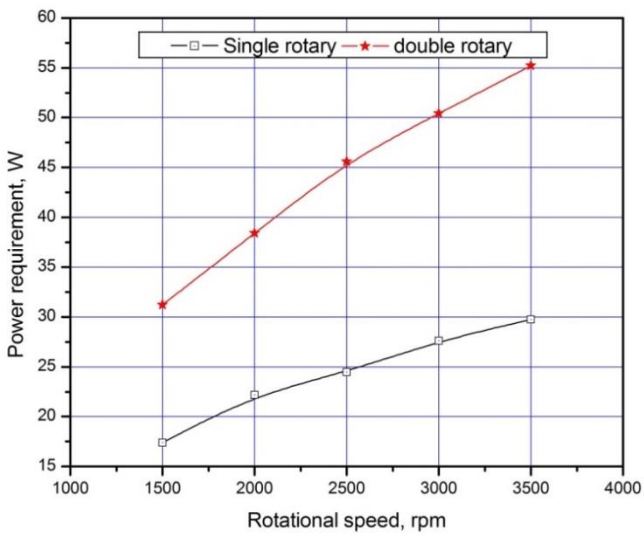

Fig. 4. The power requirement for single and two electric rotary cage atomizer at different rotational speed.
Source: Authors' determination.

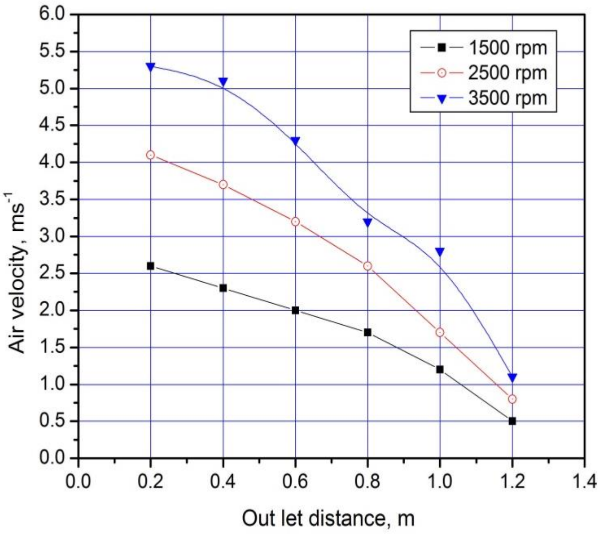

Fig. 5. The produced air velocity from single developed electric rotary cage atomizer at different rotational speed.
Source: Authors' determination.

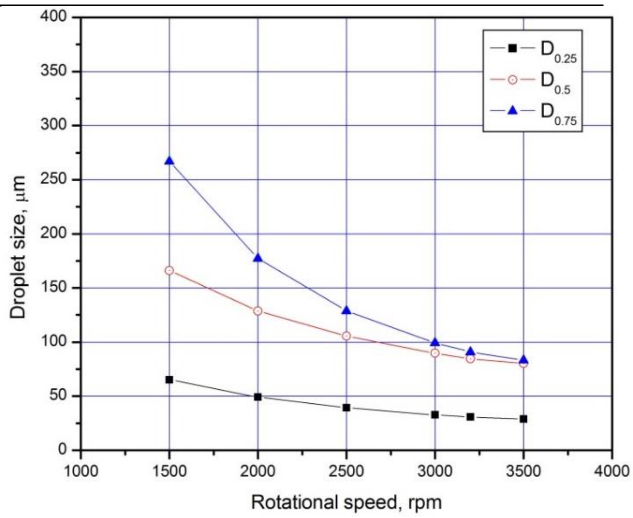

Fig. 6. The droplet size predicted of developed electric rotary cage atomizer at different rotational speed at maximum air velocity 5.3 ms^{-1} and maximum flow rate 1.4 l min^{-1}.
Source: Authors' determination.

Result of the theoretical model to predicate the droplet size

The result of the predicted droplet size $D_{0.25}$, $D_{0.5}$, and $D_{0.75}$ listed and indicated in Figures 6 and 7 and table 1 and 2. The increasing of rotational speed tends to decrease the volume medium diameter $D_{0.5}$, and droplet size $D_{0.25}$, and $D_{0.75}$. The model may able to study the effect of the rotational speed of electric rotary cage atomizer, flow rate and air velocity produced in air assisted sprayer. Figure 5 display the effect of different rotational speed at maximum air velocity 5.3 ms^{-1} and maximum flow rate 1.4 l min^{-1} on the droplet size predicted of developed electric rotary cage atomizer. The values of $D_{0.25}$, $D_{0.5}$, and $D_{0.75}$ were 66.17, 166.07 and 266.91μm at rotational speed 3,500 rpm respectively. Also, Figure 6 display the effect of different rotational speed at low air velocity 0.5 ms^{-1} and maximum flow rate 0.4 l min^{-1} on the droplet size predicted of developed electric rotary cage atomizer. The values of $D_{0.25}$, $D_{0.5}$, and $D_{0.75}$ were 125.32, 251.72 and 364.39 μm at rotational speed 1,500 rpm respectively. It noticed that, it could be able to produce different droplet spectrum from electric rotary cage atomizer and may be used in different application not only in agricultural field.

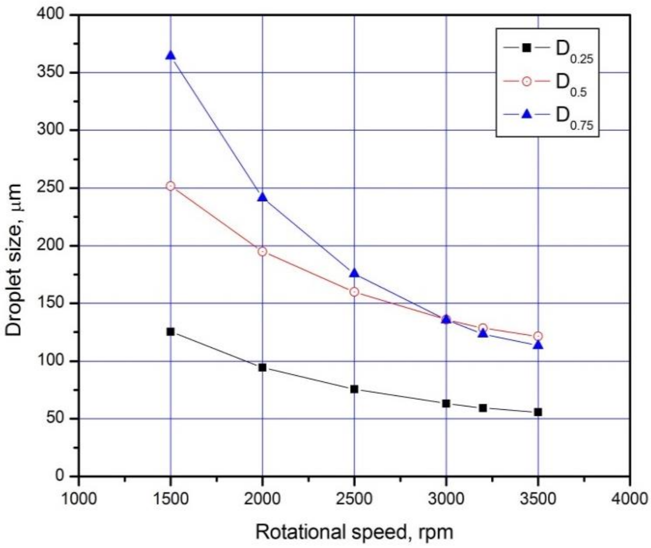

Fig. 7. The droplet size predicted of developed electric rotary cage atomizer at different rotational speed, low air velocity 5.3 ms^{-1} and low flow rate 1.4 l min^{-1}.
Source: Authors' determination.

Table 1 indicated the predicted values of droplet size under different operating conditions. The increasing of the air velocity (U), rotational speed (Ω) and liquid flow rate tends to decrease the droplet size $D_{0.25}$, $D_{0.5}$, and $D_{0.75}$. The values of droplet size $D_{0.5}$ were 251.72 at operating condition 0.4 L min^{-1}, 1,500 rpm and 0.5 ms^{-1} air velocity compared with droplet size $D_{0.5}$ 80.23 at operating condition 1.4 L min^{-1}, 3,500 rpm and 5.3 ms-1 air velocity.

Table 2 displayed the values of droplet size $D_{0.25}$, $D_{0.5}$, and $D_{0.75}$for maximum and minimum rotational speed at different trails operating conditions.

Table 1. The predicted values of droplet size under different operating conditions

$D_{0.75}$	$D_{0.5}$	$D_{0.25}$	Ω, rpm	Q, l m^{-1}	U, ms^{-1}	Ω_{max}	Q_{max}	U_{max}
341.39	251.72	107.32	1,500	0.4	0.8	3,500	1.4	5.3
215.17	170.36	73.52	2,000	0.6	1.2	3,500	1.4	5.3
146.37	126.98	51.23	2,500	0.8	2	3,500	1.4	5.3
110.98	100.27	41.76	3,000	1	2.3	3,500	1.4	5.3
95.01	89.12	34.09	3,200	1.2	3.7	3,500	1.4	5.3
85.50	80.23	31.02	3,400	1.4	4.3	3,500	1.4	5.3

Source: Own results.

Table 2. Display the values of droplet size $D_{0.25}$, $D_{0.5}$, and $D_{0.75}$for maximum and minimum rotational speed at different trails operating conditions

Trail	$D_{0.25}$	$D_{0.5}$	$D_{0.75}$	air speed, ms^{-1}
flow 1.4 l/min rotational speed 3,500	61.58	78.19	110.21	0.5
	46.05	78.19	97.74	1.2
	38.87	78.19	91.12	2
	37.1	78.19	89.39	2.3
	30.14	78.19	82.04	4.3
	28.12	78.19	79.72	5.3
flow 0.4 l/min rotational speed 1,500	0.5	125.44	251.72	364.13
	1.2	93.8	251.72	322.92
	2	79.17	251.72	301.06
	2.3	75.58	251.72	295.34
	4.3	61.4	251.72	271.05
	5.3	57.28	251.72	263.38
				Flow rate, $Lmin^{-1}$
air velocity 5.3 and rotational speed 3,500	0.4	24.72	118.52	78.67
	0.6	25.77	103.59	79.01
	0.8	26.55	94.15	79.25
	1	27.16	87.43	79.43
	1.2	27.68	82.3	79.59
	1.4	28.12	78.19	79.72
air velocity 0.5 and rotational speed 1,500	0.4	125.44	251.72	364.13
	0.6	130.79	220.01	365.7
	0.8	134.72	199.97	366.82
	1	137.86	185.69	367.69
	1.2	140.47	174.79	368.4
	1.4	142.72	166.07	369

Source: Own results.

CONCLUSIONS

It could be summarized that the increasing the rotational speed tends to increase the power requirements for developed electric rotary cage atomizer. As well as it is essay to control the droplets and air velocities by changing the power sources of the rotary cage atomizer using the manufactured control unit. Also, their maintenance will be able and very cheap compared with hydraulic rotary cage atomizer. The increasing of rotational speed tends to decrease the volume medium diameter $D_{0.5}$, and droplet size $D_{0.25}$, and $D_{0.75}$. The model may able to study the effect of the rotational speed of electric rotary cage atomizer, flow rate and air velocity produced in air assisted sprayer. The developed rotary cage atomizer could be able to produce different droplet spectrum and may be used in different application not only in agricultural field.

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