Wear on circular orifice plate of hollow-cone type agrochemical spray nozzles

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Abstract: An orifice plate of spray nozzles changes pressurized agro-chemical liquid spray into the finer droplets in order to accomplish the application of pesticide on the field crops. Application rate of pesticide per unit area (L ha^{-1}) is an important pre-defined parameter for a particular crop, which is governed by the combined effect of flow rate per unit time (L min^{-1}) and the time to cover a unit area (hr ha^{-1}). An experiment was conducted with hollow-cone type agro-chemical spraying nozzles, which have plastic, stainless steel and ceramic as tip-materials, and each material with three replications, was tested at three different spraying pressures (3.5, 7.0, and 10.5 kg cm^{-2}) under the controlled environment. The study has revealed that due to the wear, orifices of hollow-cone nozzles fail to maintain a constant rate of flow against the test liquid spray (an abrasive solution of china clay mixed 60 g L^{-1} with clean water) with the time of usage. Material of construction for orifice plates has shown significant effects of wear with the usage of time and recorded minimum in ceramic plate followed by stainless steel and plastic against each hydraulic pressure, respectively. Wear rate also reported varying nearly square root of the time. The respective study may facilitate manufacturers to provide the useful life of agro-chemical based nozzles in terms of hours of usage.

Keywords: circular orifice, orifice material, spray pressure, wear rate and time

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1 Introduction

Agrochemical application is an inevitable task to perform at least twice or more in between the advancing stage of plant and its maturity before harvesting. These agrochemicals are usually applied in the form of spray solutions such as liquid fertilizers, soluble fertilizers mixed with water or other solvent etc. onto the field crops. An accurate quantity of spray may result in higher crop productivity and the quality of field produce. Nozzles are designed in such a way that they produce desired flow rate per unit time (L min^{-1}) when operated under the range of recommended spraying pressure. An ideal nozzle shall produce the desired flow rate (L min^{-1}) throughout the spraying operation, so that a balanced application rate (L ha^{-1}) throughout the crop area could be maintained. However, a nozzle fails to maintain the desired flow rate due to the wear of the nozzle orifice when subjected under a constant spray pressure. An orifice plate holds the in-built pressure and emits liquid into the form of spray droplets. Orifice plate works best up to a certain time of usage. Since the operating time of sprayers is limited in a year, the time of usage alone may not be an appropriate parameter to express the worn-out life of an orifice plate. However, the percentage variation in flow rate through nozzle with usage of time is the best indicator to find the useful life of orifice plate before the nozzle worn-out (Krishnan et al., 2004). Although some nozzle manufacturers recommend the replacement of old nozzles with new nozzle when the increase of flow rate of old nozzle reaches out 10% of the initial flow rate, many pesticide applicators tend to use nozzles longer. An orifice is assumed to be worn-out as the flow rate exceeds

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15% of the initial flow rate of that new orifice when operated at a particular pressure (Krishnan et al., 2004). Droplet size distribution is irrespective of the material for new nozzles having the same capacity and becomes dependent of materials as wear rate on nozzles advances with time (Reichard et al., 1992).

Plastic and stainless steel type nozzles with circular orifice plate were usually in demand of agrochemical applications commercially (Tiwari 2016) and the practice of pesticide application with nozzles of ceramic material was recently started. Study was done to investigate the useful life of various orifice plates of hollow-cone nozzles, which have three different materials *viz.* plastic, stainless steel and ceramic. Hollow-cone nozzles are most suitable in the pesticide spray as they produce finer droplets and used with whirl devices which results an appropriate pressure drop (Bindra and Singh, 1977; Kepner, 2005). All three orifice plates, with three replications of each, were tested under the long run wear test at the operating pressures of 3.5, 7.0, and 10.5 kg cm^{-2}, respectively. As mentioned above, in order to study orifice wear, the compare of flow rates of used nozzles with the flow rates of new nozzles of the same size and type was the best way to predict the wear on the orifice plates (Krishnan et al., 2004). Therefore, the flow rate was used as an indicator of orifice wear of hollow-cone nozzles having different orifice plates. The factors that cause wear are the operating pressure, material of construction of orifice of nozzle-tip, shape and size of the orifice and the concentration of the spray solution (Zhu et al., 1995).

From the pre-independence era of India, studies were geared up on the wear of nozzles in the world. Since then, many studies have been taken place. Many researchers (Ozkan 1992; Womac 2000) studied spray distribution pattern across the swath and stream droplets size. Others (Reichard et al., 1991; Zhu et al., 1995; Sukumaran et al., 2013) investigated the effect of flow rate with the usage of time of nozzles. This study is nascent in India which comprises materials of construction, operating pressures, flow rates and physical hardness of the spray solution (Sukumaran et al., 2013). The test was carried out with an abrasive material (china clay powder) mixed with the fresh water having minimum foreign matter (ASAE, 1998).

Thus, the objective of the study was to distinguish hollow-cone nozzles with circular orifices based on the material of their constructions, wear rate, spray pressure and the life of usage.

2 Materials and Methods

Nozzles were selected randomly from the inventory of nozzles in ASPEE foundation, each with fifteen numbers, having plastic, stainless steel and ceramic as orifice tip-materials, respectively. Figure 1 shows a complete set of components through which a nozzle is made (components are self-explanatory). Out of fifteen, three sets of nozzles of each material were selected for testing which showed negligible variations of initial flow rates within the materials, respectively (ASAE, 1998; Sukumaran et al., 2013). All tangible materials were tested under the liquid spraying pressure of 3.5, 7.0, and 10.5 kg cm^{-2}, respectively. Thus, total twenty seven samples were dealt into the study.

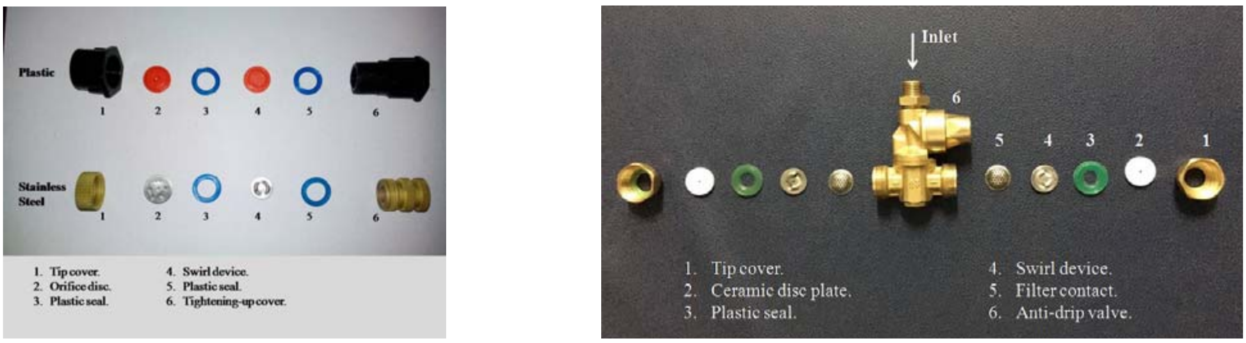


Figure 1 Components of various hollow-cone nozzles consisting different orifice plates

As per the Bureau of Indian Standards, IS 3652:1995, nozzles were sprayed with the clear water for 15 minutes of short duration before mounting them under a long run wear test. This was done by mounting samples on patternator (Figure 2) haivng 1.3×1.0 m of size. Physical and operatonal parameters like flow rates, spray angle swath width were measured on patternator to ensure the similarity among sample nozzles of same materials before mounting them for the long run wear test. A spray tank of 166 L capacity was used to test wear rate of nozzle orifices, on which three nozzles of same material were mounted at a time. Two-third of the tank was filled with the spray solution contains china clay mixed at the rate of 60 g L^{-1} of clean water as abrasive material (ASAE, 1998). Thus, the quantity of 6.64 kg of china clay was mixed with 110.67 L of clean water, i.e. two-third of the capacity of spray tank.

A schematic diagram of spray tank, fitted with test assembly, has shown with working components along with the actual test rig (Figure 3). A positive displacement piston type pump was attached at the bottom having suction capacity of 27 L min^{-1}. A pressure regulator was given to control the operating pressure of spraying provided with analogue type pressure indicator (shown in Figure 3) so that the desired amount of spray liquid supply could be given to the testing nozzle samples (three at a time). China clay is partially soluble into the water. Therefore, the bypass line of spray mixture was used as hydraulic agitator to keep abrasive material aggressive during the long run wear test. There were the traces of wear on abrasive material after a certain period of usage into the spray solution. The tank mixture was therefore advised to be replaced at the time when the flow rate through all nozzles exceeded 120% of the last measured flow rate (ASAE, 1998).

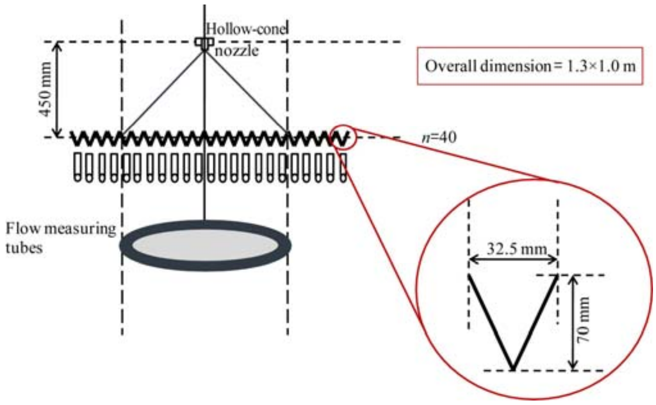
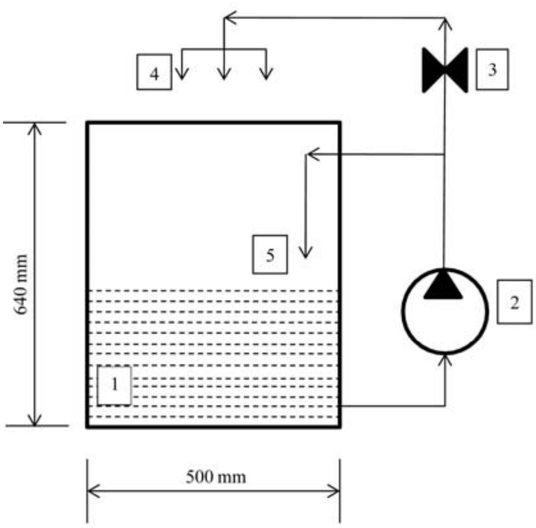
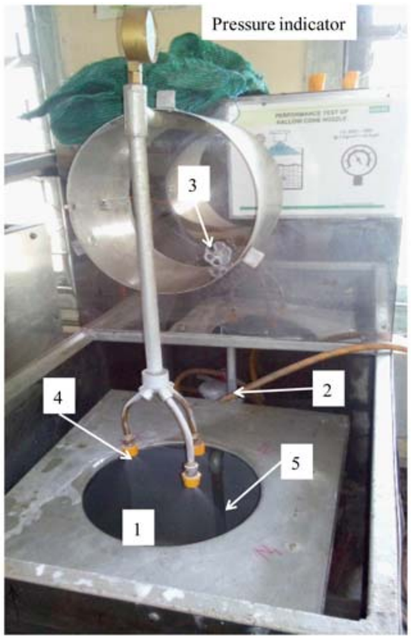


Figure 2 Schematic diagram of Patternator with dimensions (not to scale)





1. Spray mixture 2. Pump 3. Regulator 4. Nozzle discharge under pressure 5. By-pass mixture

Figure 3 Schematic diagram of spray tank of long run wear test (not to scale)

A mathematical model was developed by Zhu et al. (1995) to predict the wear rate in elliptical orifices which was used as a reference to predict the rate of wear rate in nozzles having circular orifice. The percentage increase of flow rate with the time of usage was used as an indicator of wear rate. Based on the respective study done, equation was derived which may be applicable for circular orifice plate. The derived expression to anticipate wear rate having circular orifice can be given as:

$$\eta_e = [e^{\frac{K}{(1-m)}\times t^{(1-m)}} - 1] \times 100 \tag{1}$$

where, η_e = percentage increase in flow rate, (%); 'm' is a property parameter which depends on the orifice size and its material, and fluid characteristics; '*K*' is a property parameter which depends on operating pressure, coefficient of friction between fluid and orifice and other factors including orifice material, spray formulation and orifice size; t = time, hrs.

$$m = \left[1 - \frac{(\ln B_1 - \ln B_2)}{(\ln t_1 - \ln t_2)}\right] \tag{2}$$

$$K = \frac{(1-m)B_1}{t_1^{(1-m)}} \tag{3}$$

where,

$$B_1 = \ln\left(\frac{\eta_{e1}}{100} + 1\right) \tag{4}$$

and,

$$B_2 = \ln\left(\frac{\eta_{e2}}{100} + 1\right) \tag{5}$$

The Equation (1) shows that the percentage increases of the flow rate of the circular orifice plate with respect to the time of usage. The observed percentage increase in flow rate at any time during the long run test η_{e1} and after every 5 hours, η_{e2} were used as tools to determine arbitrary constants B_1 and B_2, respectively (Equation (4) and (5), respectively). The values of property parameters, m and K (Equation (2) and (3), respectively), can be determined through solving any two simultaneous arbitrary constants B_1 and B_2 for their corresponding time t_1 and t_2, respectively. Hence, the predicted wear rate (percentage increase in flow rate) can be determined using Equation (1). For a given spray pressure, the flow rates through orifice plates of same kind were observed after every five hours of testing with clean water. The operation for a sample was stopped as the percentage increase of flow rate exceeded 15% of the flow rate of fresh nozzle of a particular kind as it was reported the limitation of a nozzle of becoming worn-out (Ozkan et al., 1992; Krishnan et al., 2004). Values of percentage increase of flow rates recorded through experiment were correlated with the corresponding values of wear rate obtained from predicting Equation (1).

3 Results and discussion

Table 1 deals with the values of constants '*m*' and '*K*', calculated through solving any two simultaneous equations of percentage increase of flow rate with respect to their consecutive time intervals, respectively.

The constant 'm' that depends on the orifice size and its material and the fluid characteristics. Research by Reichard et al. (1991) indicated that the spray pressure was inversely proportional to 't^m' and flow rate increased due to wear varied approximately with $\mathbf{t}^{0.5}$. Sztachó-Pekáry István, in 2004, has also reported that the wear rate varied approximately square root of operating time. This is clear from the Table 1 that the value of constant '*m*' is almost tending to 0.5 in all the materials when at various pressures of long run wear test. Orifice plates have greatly influenced the value of the constant '*K*' which includes the apparent coefficient of friction between the fluid and orifice material. This may be noted from the Table 1 that the K-values are 0.012418, 0.008353, and 0.005144 for plastic, stainless steel and ceramic orifices, respectively, at 3.5 kg cm^{-2} of spray pressure and obtained results have shown that plastic orifice worn-out faster than that of either stainless steel or ceramic orifice plate. This has revealed that orifice plates made of ceramic have greater capacity to stand against wear since it has shown the least value of the constant '*K*' among other materials of orifice plates. Similar findings have been reported when the test orifice plates were operated at the spray pressure of 7.0 and 10.5 kg cm^{-2}, respectively.

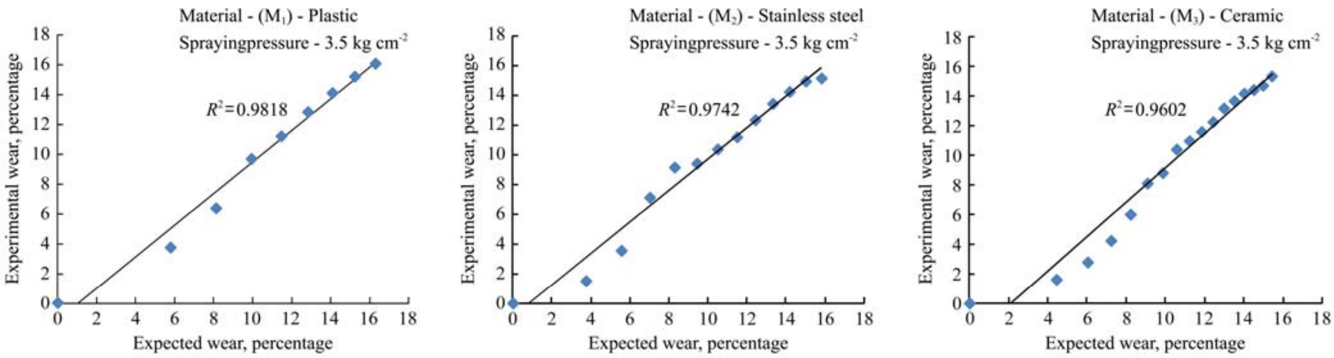
Table 1 Values of *m*, *K* and R^2 of different materials on various test pressures

Spray Pressure	Notation	Material	m*	K*	R^2
P_1 = 3.5 kg cm^{-2}	M_1	Plastic	0.52462	0.012418	0.982
	M_2	Stainless Steel	0.44295	0.008353	0.974
	M_3	Ceramic	0.56917	0.005144	0.960
P_2 = 7.0 kg cm^{-2}	M_1	Plastic	0.55088	0.01588	0.992
	M_2	Stainless Steel	0.59511	0.01361	0.990
	M_3	Ceramic	0.56179	0.00644	0.996
P_3 = 10.5 kg cm^{-2}	M_1	Plastic	0.42748	0.02054	0.999
	M_2	Stainless Steel	0.57028	0.0171	0.996
	M_3	Ceramic	0.49398	0.0068	0.988

Note:* The constants m and K were calculated through Equation (2) and (3), respectively.

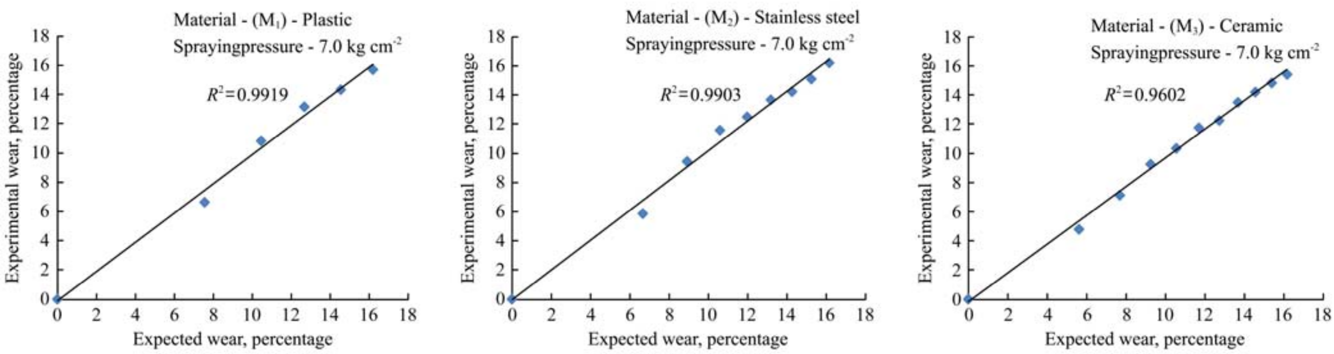
Figure 4 has shown the degree of correlation in between the expected values of percentage wear and the experimental values obtained (represented through dots) during long run wear test in plastic, stainless steel and ceramic orifice plates at 3.5 kg cm^{-2} of spray pressure.

The correlation (represented through the best fit line) has shown that the percentage wear in all materials (least in ceramic followed by stainless steel and plastic) increases comparatively slower in long run of orifice wear test than that of the expected values calculated by the predicting Equation (1). This may be due to the shape of the periphery of orifice plate which shows that wear occurs around the orifice wall was not uniform unless the flow erosion of material reached at propinquity of flow at lower spray pressure at 3.5 kg cm^{-2}. The various materials may have attained the uniform wear around the periphery of circular orifice plates faster because of higher spray pressures having degree of 7.0 and 10.5 kg cm^{-2} which could not be captured in Figure 5 and Figure 6, respectively. That is why, the values of correlations obtained at spray pressure of 3.5 kg cm^{-2} were lower than that values obtained at spray pressure of 7.0 and 10.5 kg cm^{-2}, respectively.



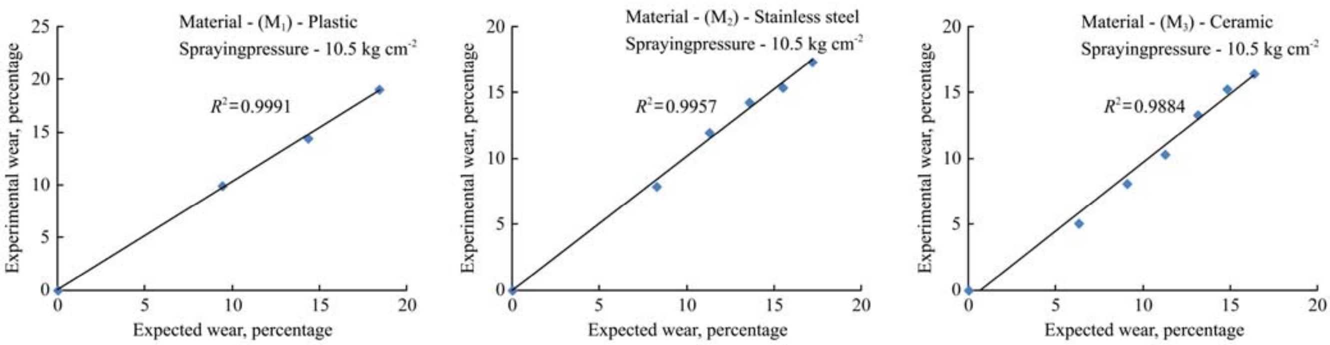
(a) Plastic (b) Stainless steel (c) Ceramic

Figure 4 Correlation between the expected and the experimental percentage wear on different orifice plates at 3.5 kg cm^{-2} of spraying pressure



(a) Plastic (b) Stainless steel (c) Ceramic

Figure 5 Correlation between the expected and the experimental percentage wear on different orifice plates at 7.0 kg cm^{-2} of spraying pressure



(a) Plastic (b) Stainless steel (c) Ceramic

Figure 6 Correlation between the expected and the experimental percentage wear on different orifice plates at 10.5 kg cm^{-2} of spraying pressure

Figure 7 has shown the time of different circular orifice plates in terms of satisfactory working hours of usage for the spray pressures 3.5, 7.0, and 10.5 kg cm^{-2}, respectively. Ceramic orifice material showed longest life of 320, 310, and 290 hours in which the percentage increase of flow rate (rate of wear) was below 15% of the initial flow rate of fresh nozzles at spray pressures 3.5, 7.0, and 10.5 kg cm^{-2}, respectively. Whereas circular orifice plates of stainless steel worn-out in 110, 70, and 45 hours and plastic in 65, 25, and 15 hours when operated at spray pressure of 3.5, 7.0, and 10.5 kg cm^{-2}, respectively.

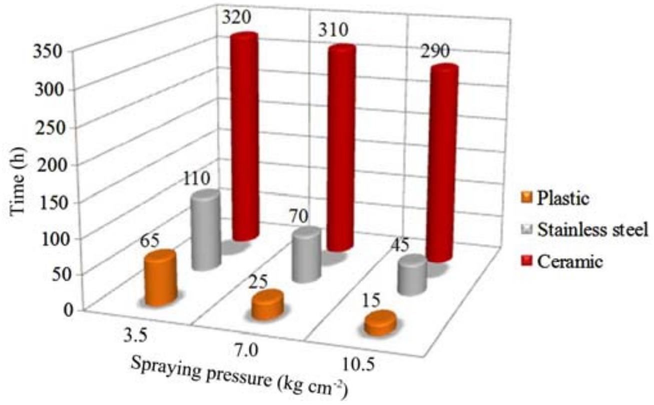


Figure 7 Graphical representation of useful working hours of different orifice plates before worn-out

Material of construction of circular orifice plate has significant effect on wear rate with the usage of time and minimum in ceramic plate followed by stainless steel and plastic. Circular orifice plates of hollow-cone nozzles made of plastic and stainless steel are suitable for spraying agrochemicals requires lower application rates at low spray pressures applications. Ceramic orifice plates, on the other hand, may be used where the high amount of agrochemical spray per unit area is required because of its immensely working hours under the lower as well as at higher spray pressure.

4 Conclusions

As reported from the above study that, the hollow-cone nozzles with ceramic orifice plate can maintain almost an accurate flow rate over much longer time as compared to either stainless steel or plastic, thus enhances the component reliability of a sprayer or any atomization device and ensures the balanced application rate of spraying for comparatively longer period of time. Farmers in many developing nations with rich diversity in agricultural practices, including India, are not educated enough to gauge the wear rate in nozzles and to count the losses occurred due to excessive consumption of pesticides. Thus, the manufacturers shall indicate the life of agro-chemical spray nozzles in terms of hours of usage through more aggressive testing of nozzles. India is today considered as a Newly Industrialized Country (NIC), Indian manufacturers could take this initiative as faster as possible. In order to determine the quality of material withstanding against high pressure and abrasive spray solutions, the nozzles, coated with some abrasive resistant nano-materials, may also be tested.

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