J. Agr. Sci. Tech. (2015) Vol. 17: 1071-1082

Low Energy Rotary Nozzle: An Energy and Water Saving Device for Field Crop Irrigation

A. Rahman[1]

ABSTRACT

Pressurized irrigation technologies of course have the potential to raise the productivity of land and water; but, these technologies could not popularize among the smallholders who own millions of farms worldwide. In developing pressurized irrigation technologies, particularly for field crops irrigation, researchers and manufacturers have developed more specialized and expensive technologies with sophisticated and intricate hardware. These new technologies have benefited only the large and wealthier farmers leaving the smallholders to remain confined with conventional methods of irrigation. This paper discusses the design, performance, and applicability of a low-pressure water sprinkling nozzle, named LERN. This nozzle can be operated satisfactorily over the operating pressure range of 79-117 kPa. The water application rate of LERN is reasonably high, i.e. 20-23 mm h^{-1}; therefore, field crops such as rice, wheat, oil seed etc. can be irrigated quickly and efficiently even at small plots, where available options such as impact sprinklers are, in general, neither feasible nor applicable due to high pressure requirement (196 - 294 kPa), non-divisibility over small plots, and relatively high cost of pumping and system networking. Since the pressure requirement at the nozzle head reflects overall cost of a pressurised irrigation system, LERN holds greater promise in development of a cost effective pressurized irrigation system for irrigating field crop even at small plots.

Keywords: Coriolis force, Developing world, Jet breaking, Operating pressure, Smallholders.

INTRODUCTION

Globally, there are about 525 million farms, of which, smallholdings of less than two hectares constitute about 85% (Oksana, 2005). Out of this, more than 90 percent are located in developing countries (Chand *et al.*, 2011). Theses smallholders are alone providing more than 80% of the total food consumed in the developing world (IFAD, 2013). Smallholders are the biggest users of groundwater for mitigating devastating effects of extended dry seasons and regular droughts (Siebert *et al*., 2010; Garduno and Foster, 2010). Excessive use of groundwater has led widespread groundwater resource depletion, water quality deterioration, aquatic ecosystems damage and a threat to world food production (Foster *et al*., 2009; Burke and Moench, 2000). Therefore, for groundwater sustainability, the key is to enhance water use efficiency and water productivity. These can only be achieved if pressurized irrigation systems are adopted widely for improved management of on-farm irrigation water (Liu *et al.*, 2013; Al-Ghobari, 2014). As per Hillel (1989) and Keller *et al*. (2001), the pressurised irrigation technologies are well suited when farmers are more dependent on groundwater. But, despite these apparent benefits, adoption and diffusion of pressurized

[1] ICAR Research Complex for Eastern Region, Division of Land and Water Management, Patna-800 014, Bihar, India. e-mail: rahman_patna@yahoo.co.in

irrigation technologies are far below the existing potential level (Palanisami *et al*., 2011). The main reason behind this shortfall is the initial investment cost of existing pressurized irrigation systems (Shahzadi, 2013).

Most of the developed pressurized irrigation technologies are sophisticated and highly mechanized; require high operating pressures and, therefore, necessitating high pressure pumps, high pressure bearing pipe networks, and associated system components (Phocaides, 2000; Sourell *et al*., 2003). These requirements translate into high investment on pumping, pipes, fittings, energy, labour, and maintenance (Romero *et al*., 2006). For the majority of smallholders, these associated capital expenditures can seldom be justified (Hillel, 1989). Therefore, if the pressurised irrigation technologies are to be adopted by smallholders in true sense, then, these technologies should be of low cost and divisible, simple in design and operation, have few manufacturing parts, easy in operation and maintenance, and moreover, should require low operational energy (Keller and Bliesner, 1990; Cornish, 1998).

Several attempts have been made earlier to develop simple irrigation technologies with major emphasis on reducing the operating pressure, use of low pressure bearing pipe network, modifying pipe network system, emitters/nozzles, filters, fittings and accessories to reduce overall cost of the systems (Suryawanshi, 1995; Lyle and Bordovsky, 1981; Polak *et al*., 1997). However, despite many apparent benefits, these systems could not popularize among smallholders due to high mechanization, large farm applicability, suitability mainly for row and plantation crops not for field crops traditionally grown by the smallholders to meet their daily households' food requirement (Visalakshi *et al*., 2002). Keeping these facts in view, this author developed a nozzle, named Low Energy Rotary Nozzle (LERN) which can be used for irrigating field crops even at small farms, where existing sprinklers such as impact sprinkler, used for field crop irrigation, are not applicable due to its non-divisibility at small farm and associated energy requirement.

MATERIALS AND METHODS

Design Methodology of LERN

The schematic of Low Energy Rotary Nozzle (LERN) is shown in Figure 1. It is a multi-armed nozzle developed with brass material. In this nozzle, curved arms are joined on an oblate spheroidal shape drum at different angles, called "trajectory angles", in vertical plane with respect to the horizontal plane bisecting the drum and passing through the center of the drum. The purpose of assigning of different angles was to throw the jets at different points across the wetted area to improve water application. The arms were given bends (Figure 2) to have tangential components of jets' velocity. These tangential components give reverse angular momentum to the nozzle and the rate of change of this moment produces torque. This is the torque which rotates the nozzle about the riser, if mounted on the riser with socket and bush arrangement. The radial components to exert reverse momentum; however, the net torque

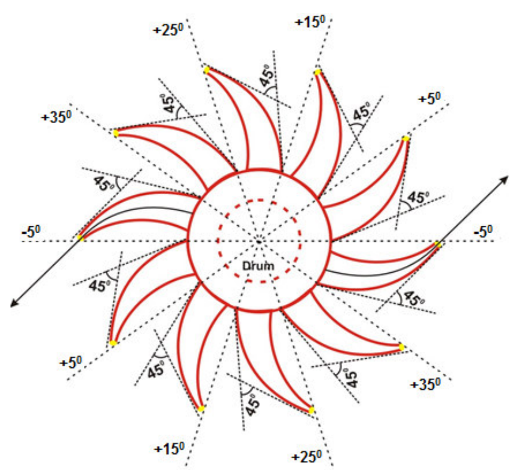

Figure 1. Schematic diagram of LERN.

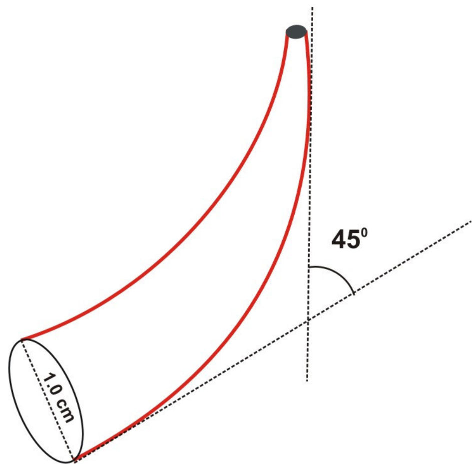

Figure 2. Schematic diagram of an arm of LERN.

is zero, as line of action passes through the rotation axis.

Since a rotary frame is non-inertial, many pseudo forces govern the jets. These forces are the *Euler*, *centrifugal,* and the *Coriolis forces* (Battin, 1999; Menke and Abbott, 1990; Takwale and Puranik, 1980). Mathematically; $\boldsymbol{F_{Coriolis}} = -2m\boldsymbol{\Omega}\times\boldsymbol{v}$; $\boldsymbol{F_{centrifugal}} = -m\boldsymbol{\Omega}\times(\boldsymbol{\Omega}\times\boldsymbol{r})$ and $F_{Euler} = -m(d\boldsymbol{\Omega}/dt)\times\boldsymbol{r}$; where, $\boldsymbol{v}$, $\boldsymbol{r}$ and m are the velocity, position vector and mass of the jet element, respectively, and $\boldsymbol{\Omega}$ is the angular velocity of the nozzle. The magnitude of pseudo forces depends on the angle made by a jet with the direction of local rotation. In static state $\boldsymbol{\Omega}= 0$, and therefore all the three forces are absent. The *Euler force* is effective till $\boldsymbol{\Omega}$ changes. The *centrifugal force* pulls the jets away from the riser; whereas, the *Coriolis force* is perpendicular to $\boldsymbol{v}$ and rotational axis and responsible for curling the jets around the axis of local rotation. If $\boldsymbol{v}$ is parallel to the direction of local rotation, then, there is no Coriolis deflection. However, if $\boldsymbol{v}$ is perpendicular to the direction of local rotation, then, Coriolis deflection is of maximum value. Therefore, if all the arms would have joined with the trajectory angle of 0°, the angle between $\boldsymbol{v}$ and local rotation for all the jets were of 90°. Under this condition Coriolis deflection on the jets would have been of maximum and all the jets were tending to converge near the riser. This could be diminishing the water application uniformity and throw diameter. Again, if arms were placed at high trajectory angle, then, while in rotation, the effective angle between the jets and local rotation would always be less than 90°. Under this condition, the Coriolis deflections were less compared to its maximum value. Simultaneously, the range of jet throw was increased due to increase in projection angle. The two desired impacts reinforces in tandem, as the trajectory angles were increased further. However, as per Solomon (1990), in absence of air drag, the 45° trajectory angle gives the maximum throw, but due to the air resistance encountered by a water jet, the trajectory angle at which maximum throw is achieved is generally less than 45° and just over 30°. In view of this observation, the combinations of many trajectory angles, ranging from -15°~ +40° were tried. The negative trajectory angles were opted to improve the water depth near the riser. The testing results showed that the maxim trajectory angle should be nearly 35°, as further increase slowdowns the nozzle due to reduction in torque strength. For appropriate volume of water near the riser, -5° was the most appropriate angle. Overall observations showed that, for the ten arms nozzle, the most appropriate set of angles in view of water application uniformity, were of -5°, +5°, +15°, +25° and +35° with opposite arms at equal trajectory angle. Assignment of the same angle to the opposite arm was to maintain design symmetry.

To determine the shape of drum, different types of drum such as spherical, cylindrical and oblate spheroidal shape drums were tested. Out of various shapes, the oblate spheroidal shape drum was the most appropriate in view of smooth outflow of water and better rotational stability. The size of drum were selected on the basis of two observed factors: (a) large size diminished the water application depth around the riser, (b) with small drum, the joining of arms with good base area was difficult, as small base area lead throttling in outflow. A series

of experimentation showed that the appropriate size of drum should have major and minor axes of 5.5 and 3.5 cm, respectively.

The nozzle arms were taken up of conical shape. This shape was chosen to get high velocity jets for better rotational speed and therefore better jets breakup and good value of radial throw. Theoretically, the angle of bend should always be in between 0° and 90° with radial direction. The two extremities suggest that the 45° bend would be an appropriate angle. The orifices were chosen of circular shape, as this shape usually produces greater wetted radius (El-Berry *et al.*, 2009). To select the arms' length, some factors were taken into account: (a) minimum length minimizes the air drag resistance; (b) length should be of such value so that the desired bend could be made, and (c) the arm length should be of minimum value, otherwise, jet could have traversed longer distance from the riser before breaking and, therefore, considerable area near the riser would remain dried. Different combinations of lengths, i.e. 3.0-7.0 cm, were tested. Finally, it was observed that, out of different combination, the most appropriate length was 4.5 cm.

In order to decide the number of arms, prototypes of 4, 6, 8, and 10 arms with different combinations of orifice diameters (1.5- 3.5 mm) were designed and tested. Testing showed that, when numbers of arm were small, the orifice diameter had to be large to sustain high operating pressure, otherwise, the nozzle was much pressed upwards and rotation was very uneven. However, at low pressure, the rotational speed was quite low due to low jet velocity and, therefore, large size droplets were formed, as the size of droplets are inversely proportional to the jet velocity (Hills and Gu, 1989). Under various combinations and permutations, it was found that the 10 arms nozzle with 2.0-2.5 mm orifice diameter was the most appropriate combination for the operating pressure close to 98 kPa.

Further, the incoming water stream first strikes the upper surface of the drum and then decelerates in the original direction. Water is then accelerated in the radial direction for flowing off sideways through the openings at the bottom of the arms. Due to diversion of flow, water produces some force normal to the top surface of the drum. This force presses the nozzle upwards which could counter balance the nozzle weight, otherwise rotation might not be smooth enough. Hence, the weight of the nozzle itself has definite bearing on overall performance of the nozzle. Since, the internal flow of water is quite complex, the decision over the appropriateness of the weight can only be decided on experimental basis. In the entire development, the weight of the developed nozzle was in the range of 120 -130 g. The summary of design parameters of LERN is reported in Table 1.

Testing Methodology and Experimental Setup

In general, the hydraulic characteristics of an individual sprinkler have much bearing on overall quality of irrigation. Some of the important hydraulic parameters which serve as performance indicators of a nozzle, are the head discharge relationship, radial water distribution and radial throw (Kincaid, 1991; Sourell *et al.,* 2003). These indicators can be determined by *single nozzle* test (Li and Hiroshi, 1998; Abo-Ghobar and Al-Amoud, 1994). Another important indicator is the uniformity pattern of the applied water over the wetted area. This is one of the most important criteria for achieving good irrigation efficiency (Ring and Heerman,

Table 1. Design parameters of Low Energy Rotary Nozzle .

Shape of drum	Oblate spheroidal
Size of drum	5.5 cm (Major axis), 3.5 cm (Minor axis)
Number of arms	10
Length of arm	4.5 cm
Curvature of arm	45°
Trajectory angles	-5°, +5°, +15°, +25° and +35°
Weight of device	120-130 g
Material	Brass

1978). Christiansen (1942) developed a formula as follows:

$$CU = 100\left(1 - \frac{\sum\left|x_i - \bar{x}\right|}{n\bar{x}}\right)$$

Where, *CU* is Christiansen's coefficient of uniformity; x_i is the depth in equally spaced catch cans on grid; x is the mean depth of water caught in the cans, and n is number of collectors measured,

This formula is widely used to assess water application uniformity. *CU*> 0.70 is regarded as satisfactory (Karmeli 1978; Letey *et al*., 1990). Li and Rao (2000) reported that the sprinkler uniformity below the canopy of wheat improved compared to the uniformity as measured above the canopy. This indicates that the canopy can redistribute water to achieve improved uniformity before redistribution within the root zone. In another study on winter wheat, Li and Rao (2003) found that yield was not influenced by sprinkler *CU* (coefficient of uniformity) ranging from 62 to 82%. Thus, there is a body of evidence that in agricultural systems, soil moisture uniformity is generally higher than catch can values in sprinkler irrigation.

The discharge of a sprinkler can be determined either by measuring the volume discharged per unit time or by measuring the sprinkler operating pressure with a pitot tube. In the first case, it is suggested to divert the sprinkler discharge to a graduated cylinder or other volumetric container by slipping flexible tubes over the orifice of the nozzle (Smajstrla *et al.,* 1997). Here, the first option was preferred and flow was measured keeping the nozzle static at each operating pressure before starting the test for radial water distribution. A stopwatch was used for measuring the discharge collection time. The pressure at the nozzle head was measured by pressure gauge fitted on the riser at 15 cm below the nozzle. The radial distance was measured to know the effective wetted area. In general, the irrigation system design considers the effective area covered by the nozzle in rotation. Hence, in this study, the radial distance covered while in rotation was considered. To record the radial distance, the distance of the last catch can, used for catch volume observation, from the riser was considered.

To observe radial water distribution pattern, cylindrical catch cans of 16.5 cm base diameter and height of 15 cm (Tarjuelo *et al*., 1999; Smajstrla *et al.,* 1997) were placed radially. The first catch can was placed at 20 cm away from the riser and thereafter a series of catch cans were placed without any gap. The height of riser was kept at 1 m and the test duration for each observation was half an hour. After completion of every test run, the volume of water received in the catch cans were recorded in mL. Each set was repeated for three times and the observed values were averaged to avoid any error.

In *block test,* there were two laterals at 8 m apart and had the provision of four risers. Hence, a grid of 8×8 m was formed. Catch cans were placed at a distance of 1 m apart (row to row and column to column). Each riser had the provision of pressure gauge, placed 15 cm below the nozzle. Before the start of each test run, the desirable operating pressure was ensured through pressure gauges by keeping all the four nozzles in static condition. Once the desirable operating pressure was achieved, the sprinkling nozzle was freed to rotate on its own. The test duration for each test was half an hour. Total of 49 catch cans were used for each test run. Each test was undertaken for three times at the corresponding operating pressures to avoid errors. Volumes of water in different catch cans were collected starting from the centre of the grid to compute uniformity coefficient (CU).

All testings were performed in an indoor laboratory established under standard guideline by National Agriculture Technology Project (NATP). The testing setup was comprised of tubewell as a source of water, attached with a 5 HP. submersible pump connected directly to the main pipeline for feeding water to experimental setup. A bypass arrangement at the delivery side of the pump was provided to divert the unwanted discharge and also to avoid any fluctuation in pumped

water to experimental setup. Standard *GI* pipes were used to convey water from pump to the main experimental setup. There was also provisions for sand and screen filters. Since the experimental area was located inside a big hall, wind effect was negligible. During the testing, the ambient temperature of testing hall was in the range of 30-35°C.

RESULTS AND DISCUSSIONS

As water was allowed to flow through the nozzle at certain pressure, the rotary motion was induced in the nozzle. The pressure at which rotary motion started was 19 kPa. But, in view of small radial throw, inadequate jet breaking and poor water distribution; performance testing were undertaken at 39 kPa and above. As the operating pressure increased, many droplets were formed due to the mean diameter of droplets being inversely proportional to the jet's velocity relative to the surrounding air (Kohl, 1974; Wong *et al*., 2004). The water near the periphery of the jet resulted in small droplets while the water near the riser with the lowest velocity relative to the air produced large droplets. As the speed of smaller droplet decreases more rapidly than the larger droplet, the droplets falling closer to the nozzle were much smaller than the droplets placed farther from the nozzle. The water sprinkling view of LERN is shown in Figure 3.

Figure 3. Water sprinkling view of LERN.

In single nozzle test, the nozzle was evaluated for radial water distribution pattern over the pressures range of 39-117 kPa. The radial water distribution pattern at the operating pressures of 39, 58, 79, 98, and 117 kPa is shown in Figure 4. It is observed that, at low operating pressure, the volume of water received near the riser was low and most of the water was collected in the middle region of the wetted area. This pattern could be

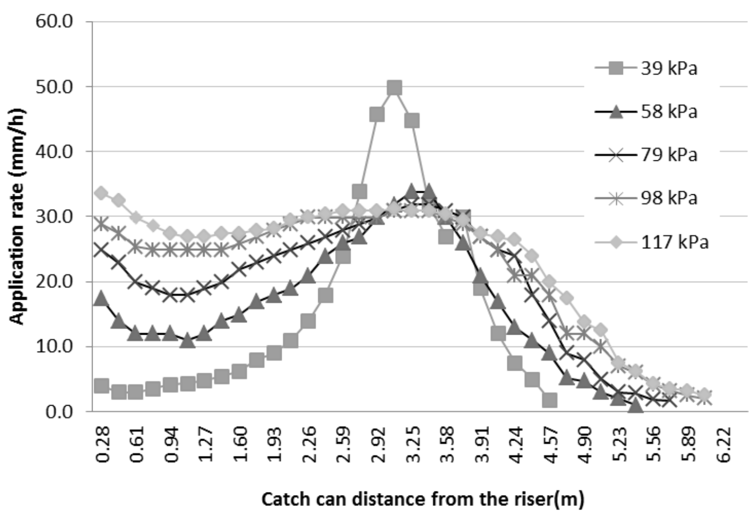

Figure 4. Radial water distribution pattern of LERN at varying operating pressures.

attributed to less jet breaking and formation of large droplets. At high pressure, particularly above 58 kPa, increasingly smaller droplets were formed due to increase in jet velocity and, consequently, the rotational speed, which tends to be collected near the riser. This improved the water volume near the riser. A much better pattern was observer over the operating pressures, ranging from 79-117 kPa. As the pressure was increased beyond 117 kPa, a fog like situation formed. This was undesirable, as it might incur high evaporation losses during irrigation (Steiner *et al*., 1983; Edling, 1985). This showed that the nozzle should be operated at 117 kPa or below. The effect of operating pressure on the radial throw is shown in Figure 5. The graph indicated that the rate of increase in radial throw was high when operating pressure ranged over 39-79 kPa; whereas, very small change was observed over 79-117 kPa. Thus, in view of foggy view and change in radial throw, the optimum operating pressure range of nozzle was 79-117 kPa. The discharge of the nozzle at different operating pressure is illustrated in Figure 6. Over the recommended operating pressure range, the discharge of the nozzle was 1.94-2.34 $m^3 h^{-1}$.

In the block test, nozzle to nozzle spacing was selected on account of the fact that the sprinkler irrigation systems do not uniformly apply water throughout their entire wetted area. The application depth tends to be high near the sprinkler and decreases gradually within the first 60 to 70% of the wetted radius. Beyond this, the application depth declines quickly to zero at the outer edge. Literature review showed that a good design should involve an overlap of 65-70 percent of the wetted diameter (Gabriel, 2011). At recommended operating pressure, i.e., over 79-117 kPa, the wetting diameter was 11-12.1 m, therefore, the nozzle to nozzle distance should be of 7.7- 8.5 m. In view of these observations, 8×8 m spacing was opted for block tests. The observed catch values were analyzed for estimating uniformity coefficients at different operating pressures. The mean *CU* values at the operating pressures of 39, 58, 79, 98, and 117 kPa were found to be 47.2, 63.5, 77.3, 82.6, and 84.7%, respectively. According to Little *et al.* (1993), the uniformity of a sprinkler irrigation system is good if *CU* value is between 80 and 89%. Since over the recommended pressure the *CU* values of the developed nozzle over the operating pressure range of 98 -117 kPa was between 82.6 to 84.7%, the nozzle performance was acceptable over this pressure range. However, at 79 kPa, the *CU* value was 77.3% which was below the good criteria. But, in view of Li and Rao (2003), field crop yield is not influenced by sprinkler, if *CU* is between 62 to 82%. Apart from this, the high water application rate of the nozzle (Figure 7) could be producing high subsurface uniformity.

The discharge of the developed nozzle was 3 to 4 times higher compared to impact sprinkler with added advantage of low operating pressure requirement (Figure 8) (Singh *et al*., 2010). At high water application rate, operation of sprinkler for short duration may

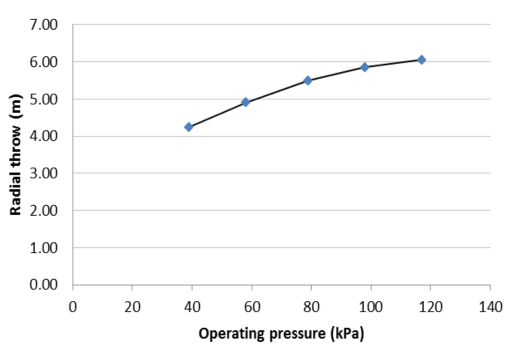

Figure 5. Effect of operating pressure on radial throw of LERN.

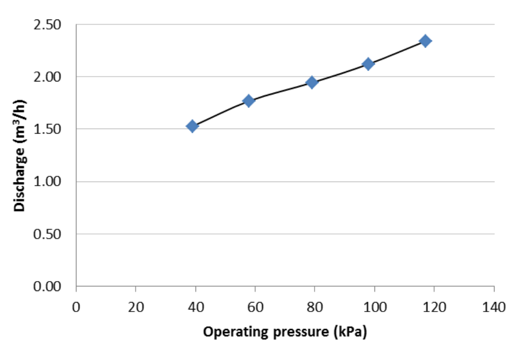

Figure 6. Head discharge relationship of LERN.

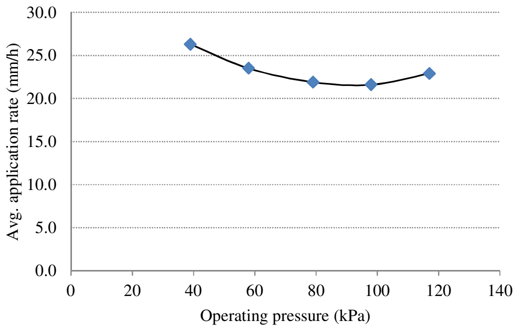

Figure 7. Average application rate of LERN at varying operating pressures.

saturate the soil more quickly without substantial loss of water through deep percolation or infiltration, a concept which is used in LEPA irrigation system to increase water application efficiency (ASAE, 1999). At high application rate, soil saturation level could be achieved quickly with minimum evaporation losses; whereas, at low application rate relatively longer duration of pumping operation will be required and, therefore, more evaporation losses would occur.

The low pressure requirement at nozzle head can facilitate the use of low pressure pumps, low pressure bearing LDPE pipes, or low cost low pressure bearing flat hose flexible pipe, PVC riser, and other low cost fittings and accessories. This could be making the system divisible and easily transportable, hence, enable the farmers to irrigate field crops grown at fragmented and scattered plots on shift basis.

Forgoing discussion shows that the rate of rotation or the angular velocity (**ω**) of a rotary nozzle has direct bearing on droplets sizes, radial throw and water application uniformity. The magnitude of $\boldsymbol{\omega}$ depends upon the operating pressure as well as on design parameters of the nozzle. Modelling of $\boldsymbol{\omega}$ in terms of these parameters could be useful in further refinement and modification of nozzle as per the needs and priorities. Figure 9 shows the schematic of nozzle with jet velocity and its components. If a jet is projected at an angle ψ with respect to tangential velocity, $u= \omega\times r$, where $\boldsymbol{r}$ is position of the orifice and $\boldsymbol{v}$ is the jet velocity. Then, the resultant velocity (V) will be the vector sum of v and u which makes an angle θ with v.

If the nozzle is at standstill, then $\boldsymbol{u}= 0$ and $\boldsymbol{V}= \boldsymbol{v}$. Further, as the nozzle starts rotating, $\boldsymbol{V}$ tends to coincide with radial direction. If $\boldsymbol{V}$ is completely in radial direction, then, there shall be no accelerating torque. This shows that the maximum torque is available when nozzle is at standstill. Again, due to $\boldsymbol{V}$, there is a reaction force of magnitude ρV in the opposite direction of $\boldsymbol{V}$ (where ρ is the density of water), which moves the point 2 in the direction of $\boldsymbol{u}$. Therefore, the rate of doing work by this reaction force ρV is $\rho Vucos\theta$. If this work is expressed as head

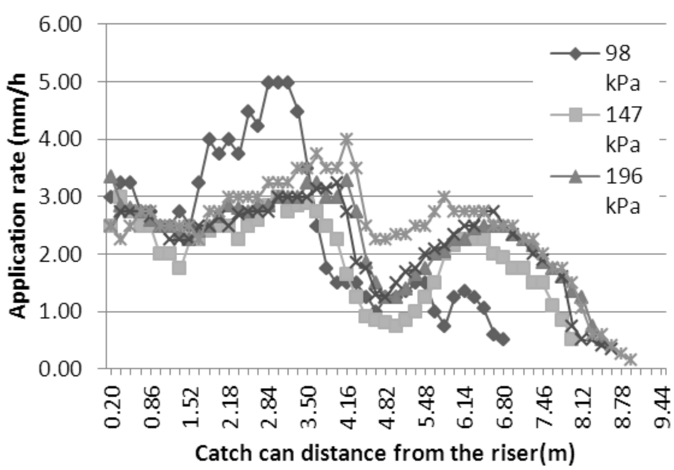

Figure 8. Radial water distribution pattern of single nozzle impact sprinkler at varying operating pressure.

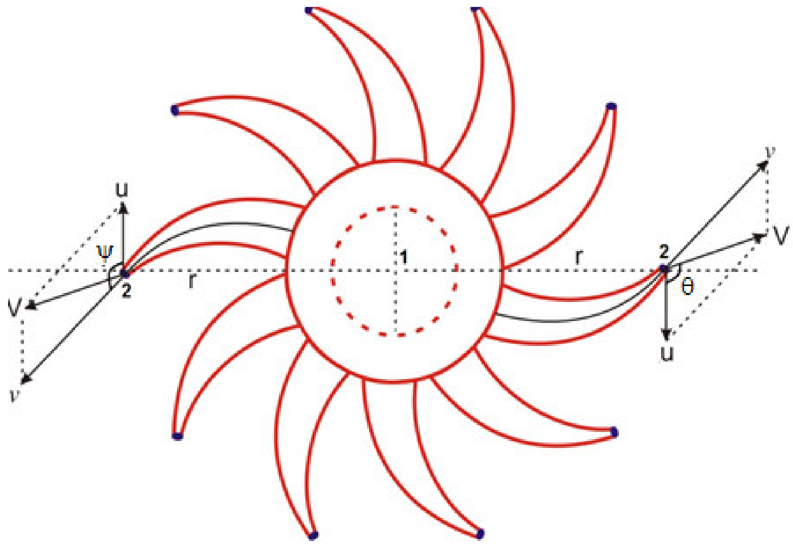

Figure 9. LERN with various velocity components while in operation.

by dividing it by ρg. Then, using gauge pressures, the Bernoulli's equation for points 1 and 2 gives:

$V^2/2 = P/\rho - Vu\cos\theta/g$ [1]

From the parallelogram theorem, we have:

$V^2 = u^2 + v^2 + 2uv\cos\psi$ [2]

$V\cos\theta = v\cos\psi + u$. [3]

Substituting for V^2 and $V\cos\theta$ from Equations (2) and (3) in Equation (1), then,

$v^2 = u^2 + 2gh$ [4]

Where, h is operating pressure head.

This expression relates the jet velocity (**v**) with angular velocity (**ω**) (as $\mathbf{u} = \omega \times \mathbf{r}$) and applied pressure head. Further, the perpendicular component of V to the radius is $V\cos\theta$, which is equal to $v\cos\psi + u$ from Equation 3. Therefore, the corresponding reaction force is obtained by multiplying it by ρ and the *total* discharge Av, where A is the sum of area of all the ten orifices. Therefore, net accelerating torque is

$\Gamma = \rho A v \bar{r} (v\cos\psi + u)$ [5]

Where,

$\bar{r} = (r/10) \sum \cos\chi_i$, χ_i is the i^{th} trajectory angle.

If the arrangement is free from the friction, then, the free running speed corresponds to zero torque or when V is completely radial and no perpendicular component, i.e., $V\cos\theta$ is zero. Then, from Equation (5):

$v\cos\psi + u = o$ or $\omega = v\cos\psi / r$ rad s^{-1} [6]

Equation (6) shows that ω is maximum if $\psi = 180°$, r is small and $\boldsymbol{v}$ is large. For the LERN, $r = 6.50$ cm, $\bar{r} = 6.15$ cm, $\psi = 135°$, $A = 0.0491$ cm^2. Therefore, at the operating pressure 39 kPa, $v = 860$ cm s^{-1}, then $\omega = 93.5$ rad s^{-1} or the rotation rate per minute (n= 894). The rotation rate per minute of LERN at different operating pressure (p) can be expressed as $n = 7.0669p + 658.57$, $r^2 = 0.9779$. In practices, these values of rpm at different operating pressure are not attainable as the system cannot be free from friction. However, this is reasonably good from analysis point of view.

ACKNOWLEDGEMENTS

Thanks to Er. A. K. Singh, Dr. A. Upadhyaya, Dr. M.A. Khan and Dr. B. P. Bhatt for their critical comments and contributions made during design, development and testing of the LERN.

REFERENCES

1. Abo-Ghobar, H. M. and Al-Amoud, A. I. 1994. Performance Characteristics of

Micro-sprinklers Irrigating Greenhouses in Saudi Arabia. *J. King Saud Univ. Agric. Sci.,* **6:** 27-37.

2. Al-Ghobari, H. M. 2014. Effect of Center Pivot System Lateral Configuration on Water Application Uniformity in an Arid Area. *J. Agr. Sci. Tech.,* **16:** 577-589
3. ASAE. 1999. Planning, Design, Operation and Management of Low Energy Precision Application (LEPA) Irrigation System. Engineering Practice X531, Am. Soc. of Agric. Eng., St. Joseph, MI 49085, 17 PP.
4. Battin, R. H. 1999. *An Introduction to the Mathematics and Methods of Astrodynamics*. American Institute of Aeronautics and Astronautics, Reston VA, 102 PP.
5. Burke, J. and Moench, M. 2000. Groundwater and Society: Resources, Tensions and Opportunities. Themes in Groundwater Management for the 21st Century. UN Dept. of Eco. and Social Affairs, New York, USA.
6. Chand, R., Prasanna, P. A. L. and Singh, A. 2011. Farm Size and Productivity: Understanding the Strengths of Smallholders and Improving Their Livelihoods. *Economic. Polit. Weekly Supp.,* **xlvi(26 and 27):** 1-7.
7. Christiansen, J. E. 1942. Irrigation by Sprinkling. Agricultural Experiment Station, University of California, *Bull.,* **670.**
8. Cornish, G. 1998. *Modern Irrigation Technologies for Smallholders in Developing Countries.* Intermediate Technology Publications in Association with HR Wallingford, UK.
9. Edling, R. J. 1985. Kinetic Energy, Evaporation, and Wind Drift of Droplets from Low–pressure Irrigation Nozzles. *Trans. ASAE,* **28(5):** 1543–1550.
10. El-Berry, A. M., Ramadan M. H., Mohsen, E. A. and Hashem, M. M. 2009. Effect of Nozzle Shape and Pressure on Droplet Size Distribution. *Misr J. Agric. Eng.,* **26(1):** 208- 223
11. Foster, S., Garduno, H., Tuinhof, A. and Tovey, C. 2009. *Groundwater Governance: Conceptual Framework for Assessment of Provisions and Needs.* World Bank/GWP GW-MATE Strategic Overview Series SO-1, Washington DC, USA.
12. Gabriel, S, Ezra, P., Oniward, S., Tendai, M. 2011. Performance of 4 mm Impact Sprinklers at Different Spacing within Acceptable Pressure Range (250-350 kPa). *Int. J. Eng. Sci. Technol. (IJEST),* **3(3):** 1858-1863.
13. Garduno, H. and Foster, S. 2010. *Sustainable Groundwater Irrigation: Approaches to Reconciling Demand with Resources.* World Bank/GWP GW-MATE Strategic Overview Series SO-4, Washington DC, USA.
14. Hillel, D. 1989. Adaptation of Modern Irrigation Methods to Research Priorities of Developing Countries. In: "*Technological and Institutional Innovation in Irrigation*", (Eds.): Le Moigne, G., Barghouti, S. and Plusquellec, H.. World Bank Technical Paper No. 94. World Bank, Washington DC, PP. 88–93.
15. Hills, D. and Gu, Y. 1989**.** Sprinkler Volume Mean Droplet Diameter as a Function of Pressure. *Trans. ASAE,* **32(2):** 471-476.
16. IFAD. 2013. *Smallholders, Food Security and the Environment: International Fund for Agricultural Development.* United Nations Environment Programme, Rome, Italy.
17. Keller. J., Adhikari, D. L., Petersen, M. R. and Suryawanshi, S. 2001. *Engineering Low-cost Micro-irrigation for Small Plots.* Report No.5. International Development Enterprises, Longmont, Colorado.
18. Keller, J. and Bliesner, R. D. 1990. *Sprinkle and Trickle Irrigation.* An AVI Book, Van Nostrand Reinhold, New York, 173 PP.
19. Karmeli, D. 1978. Estimating Sprinkler Distribution Patterns Using Linear Regression. *Trans. ASAE,* **21**: 682-686.
20. Kincaid, D. C. 1991. Impact Sprinkler Pattern Modification. *Trans. ASAE,* **34(6):** 2397-2403.
21. Kohl, R. A. 1974. Drop Size Distribution from Medium-sized Agricultural Sprinklers. *Trans. ASAE,* **15(2):** 690-693.
22. Letey, J., Dinar A., Woodring, C. and Oster, J. D. 1990. An Economic Analysis of Irrigation Systems'. *Irri, Sci.,* **11:** 37-43.
23. Li, J. and Rao, M. 2000. Sprinkler Water Distributions as Affected by Winter Wheat Canopy. *Irri. Sci.,* **20:** 29-35.
24. Li, J. and Rao, M. 2003. Field Evaluation of Crop Yield as Affected by Non-uniformity Sprinkler-applied Water and Fertilizers. *Agric. Wat. Manage.,* **59:** 1-13.
25. Li, J. and Hiroshi, K. 1998. Sprinkler Performance as Affected by Nozzle Inner Contraction angle. *Irri. Sci.,* **18:** 63-66.

26. Little, G. E., Hills, D. J. and Hanson, B. R. 1993. Uniformity in Pressurized Irrigation Systems Depends on Design, Weather and Installation. *California Agric.,* **47:** 18-2l.
27. Liu, J. P., Yuan, S. Q., Li, H. and Zhu, X. Y. 2013. Numerical Simulation and Experimental Study on a New Type of Variable-rate Fluidic Sprinkler. *J. Agr. Sci. Tech.,* **15:** 569-581
28. Lyle, W. M. and Bordovsky, J. P. 1981. Low Energy Precision Application (LEPA) Irrigation Systems. *Trans. ASAE,* **24(5):** 1241-1245
29. Menke, W. and Abbott, D. 1990. *Geophysical Theory*. Columbia University Press, PP. 124–126.
30. Oksana, N. 2005. *Small Farms: Current Status and Key Trends.* Information Brief Prepared for Workshop on the Future of Small Farms Research, Wye College, London.
31. Palanisami, K., Kadiri, M., Kakumanu, K. R. and Raman, S. 2011. Spread and Economics of Micro-irrigation in India: Evidence from Nine States. *Eco. Polit. Week. Suppl.,* **xlvi(26 and 27):** PP: 81-86.
32. Phocaides, A. 2000. *Technical Handbook on Pressurized Irrigation Techniques***.** Food and Agriculture Organization of the United Nations, Rome.
33. Polak, P., Nanes, B. and Adhikari, D. 1997. A Low-cost drip Irrigation System for Small Farmers in Developing Countries. *J. Amer. Wat. Resour. Assoc.,* **33(1):** 119-124.
34. Ring, L. and Heerman. 1978. Determining Center-pivot Sprinkler Uniformities. Paper No. 78-2001, ASAE.
35. Romero, J. N. O., Martinez, J. M., Martinez, R. S. and Martin-Binto, J. M. T. 2006. Set Sprinkler Irrigation and Its Cost. *J. Irrig. Drain. Eng.,* **132(5):** 445- 452.
36. Shahzadi, E. 2013. Investigating Factors Influencing Adoption of Pressurized Irrigation Systems by Farmers Case Study: Garmsar County, Iran. *American-Eurasian J. Agric. Environ. Sci.,* **13(1):** 115-120.
37. Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Doell, P. and Portman, F. T. 2010. Groundwater Use for Irrigation: A Global Inventory. *Hydrol. Earth Syst. Sci.,* **14:** 1863-1880.
38. Smajstrla, A. G., Boman, B. J., Clark, G. A., Haman, D. Z., Pitts, D. J. and Zazueta, F. S. 1997. Field Evaluations of Irrigation Systems: Solid Set or Portable Sprinkler Systems. The Institute of Food and Agricultural Sciences (IFAS), University of Florida, USA, *Bull.,* **266**.
39. Singh, A. K., Sharma, S. P., Upadhyaya, A., Rahman, A. and Sikka, A. K. 2010. Performance of low energy water application device. *Water Resour. Manage.,* **(24):** 1353-1362
40. Solomon, K. H. 1990. *Sprinkler Irrigation Uniformity*. CATI Publication No. 900803, Centre for Irrigation Technology, California State University, Fresno, USA.
41. Sourell, H., Faci, J. M. and Playan, E. 2003. Performance of Rotating Spray Plate Sprinklers in Indoor Experiments. *J. Irrig. Drain. Eng.,* **129(5):** 376-380.
42. Steiner, J. L., Kanemasu, E. T. and Clark. R. N. 1983. Spray Losses and Partitioning of Water under a Center–pivot Sprinkler System. *Trans. ASAE*, **26(4):** 1128–1134.
43. Suryawanshi, S. K. 1995. Success of Drip in India: An Example to the Third World. Micro Irrigation for a Changing World. *Proceedings of the 5th International Micro Irrigation Congress,* ASAE, St. Joseph, Michigan: ASAE.
44. Tarjuelo, J. M., Montero, J., Valiente, M., Honrubia, F. T. and Ortiz, J. 1999. Irrigation Uniformity with Medium Size Sprinklers. Part I. Characterization of Water Distribution in No-wind Conditions. *Trans. ASAE*, **42(3):** 665-675.
45. Takwale, R. G. and Puranik, P. S. 1980. *Introduction to Classical Mechanics.* Tata McGraw-Hill, 248 PP.
46. Visalakshi, K. P., Seekumaran, V., Susheela, P. and Santhakumari, G. 2002. *Extension Brochure Entitled: "A kit for LEPA Type Micro Sprinkler"*. Publication Unit, Director of Extension, Kerala Agricultural University Mannuthy, Thrissur, Kerala, India.
47. Wong, D. C. Y., Simmons, M. J. H., Decent, S. P., Parau, E. I. and King, A. C. 2004. Break-up Dynamics and Droplet Size Distributions Created from Spiraling Liquid Jets. *Intl. J. Multiphase Flow,* **30:** 499-520.

افشانک (فواره) دوار با انرژِی کم (LERN): وسیله ای برای صرفه جویی در انرژی و آّب برای آبیاری گیاهان زراعی

ع. رحمان

چکیده

فناوری های آبیاری تحت فشار مسلما استعداد آن را دارند که بهره وری از آب و زمین را بهبود بخشند ولی این فناوری ها در میان خرده مالکان که صاحب میلیون ها مزرعه در جهان هستند رایج نشده است. در توسعه فناوری های آبیاری تحت فشار، به ویژه برای آبیاری گیاهان زراعی، پژوهندگان و سازندگان این وسایل، فناوری هایی تخصصی و گران قیمت را که سخت افزارهایی پیچیده دارند ساخته اند . اما، تنها بزرگ مالکان و کشاورزان ثروتمند از این فناوری های نوین سود برده اند و خرده مالکان همچنان به ناچار از روش های آبیاری سنتی استفاده می کنند. در مقاله حاضر، طراحی و عملکرد و کاربرد یک افشانک (فواره) کم فشار آبیاری بارانی موسوم به "لرن" (LERN) بحث شده است. این افشانک در محدوده فشار عملیاتی ۱۱۷-۷۹ کیلو پاسکال به خوبی کار میکند. نرخ آبدهی این فواره نسبتا بالا ست (بین ۲۰ تا ۲۳ میلی متر در ساعت) بنا برا ین با استفاده از آن می توان گیاهان زراعی مانند برنج وگندم و دانه های روغنی را حتی در کرت های کوچک به سرعت و با کار آیی موثر آبیاری کرد. در این گونه کرت ها استفاده از فواره هایی مانند فواره های ضربه ای به لحاظ نیاز شان به فشار زیاد (در حدود kPa ۲۹۴-۱۹۶)، قابل تقسیم نبودنشان در کرت های کوچک، و هزینه بالای پمپاژ و احداث شبکه معمولا عملی و قابل اجرا نیست. بنابر این، از آنجا که فشار لازم در سر فواره هزینه کلی سامانه آبیاری تحت فشار را منعکس میکند، برای توسعه سامانه تحت فشار آبیاری در کرت های کوچک که از نظر اقتصادی هم برای محصولات زراعی موثر باشد، فواره LERN که با فشارکم کار می کند، امیدوار کننده تر است.