JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 17 2009

INVESTIGATION OF A MECHANICAL SPRINKLER WITH SQUARE PLANE IRRIGATION ABILITY

J. Taghavi[1]
R. Ghafoori Ahangar[2]
M. Z. Ahmadi[1]
Gh. Aghajani[1]
M. Hasirchian[1]

[1]College of Agricultural Engineering, Sari University, Iran
[2]Department of Mechanical Engineering, Iran University of Science and Technology, Iran

This paper reviews different agricultural sprinklers with squared plane irrigation ability and determines the limitations and their use as a structure for irrigation. The mechanical agricultural sprinkler with squared plane irrigation ability presents the most effective design. A number of theoretical methods are put forward to explain sprinkler characteristics and these are verified by an analysis of experimental data. A study of change in the angle of sprinkler rotation, which changes the angle of nozzle outlet and its distance of throw, leads to recommendations for the new system. By designing the follower on the cam, the angle of the nozzle is changed. The moment created by flow discharge and the atmosphere is the force for turning the sprinkler. The CATIA software is used to design and simulate the structure.

INTRODUCTION

Sprinklers play a key role in the agricultural industry and preserving green belts. Water management for farmers is necessary. Irrigation efficiency is an important factor in improvement of water management and is an economic activity. Calculating the irrigation efficiency and the irrigation water usage efficiency (IWUE) is important. In the use of rain irrigation in comparison with the other methods such as drip irrigation, the IWUE is a necessary part. One method to economize the use of water is to use a sprinkler with a scheduling plan. One factor that must be considered in using a sprinkler is the size of water droplets which depends on the nozzle characteristics and water pressure. A sprinkler with a fixed size of nozzle and angle of stream line that works with a fixed pressure, produces a known size of water drops (Al-Jamal et al., 2001). Experiments performed to date have shown that the relation between water drop diameter and distance from sprinkler is as follows (Al-Jamal et al., 2001):

$$D = 0.4587\, e^{0.1387\, x} \tag{1}$$

where x and D are the distance of water droplet from the sprinkler and the water drop diameter, respectively.

Figure 1 shows this relationship (Sudheer and Panda, 2000). Evaporation and the waste of water in irrigation by sprinklers are affected by several elements: water drop diameter, weather conditions (directly), action pressure and pressure of sprinklers (indirectly) (Kang et al., 2005). In cases where several sprinklers are used simultaneously, the following equation is recommended to calculate functional velocity (Al-Jamal et al., 2001):

$$i = \frac{39.5\, q}{Sm\; Sl} \tag{2}$$

in which i is the average functional velocity (m/hr), q represents the average exit discharge (m^2/s), Sm denotes distances between sprinklers in the mainline direction (m), and Sl is the sideways distance between sprinklers (m).

Knowing the functional velocity is effective in improvement of sprinkler function, especially when we want to use several sprinklers simultaneously. In addition to functional velocity, other factors are effective in improvement of sprinkler function. One of the most important factors is measurement of sprinkler's accuracy in irrigation of fixed areas. In point of optimum water consumption, especially in Iran, which is semiarid, a sprinkler is designed and constructed that is

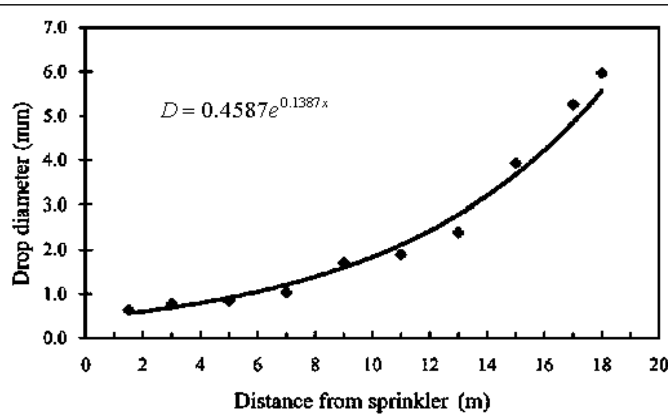

Figure 1. Drop distance versus drop diameter.

able to irrigate polygonal areas. The benefits of this sprinkler are:

1. Preventing water waste in irrigation of polygon surfaces.
2. Exact irrigation that prevents growth of weeds in unnecessary areas.
3. Exact irrigation of polygonal surfaces compared to circle sprinklers.
4. Easy change of sprinkler range by replacing the cam.

To create the ability for cultivation using these sprinklers, the following methods are used:

1. Changing the entrance pressure to rotational.
2. Changing the outgo sectional area of nozzle to rotational.
3. Changing sprinkler's outlet angle toward rotational.

To accomplish 1 and 2 requires easy access to electricity. Hills et al. (1998) have examined an irrigation machine with sideways movement to calculate the uniformity for tube sprayers, boom sprayers and rotators that have distinguished the effects of wind and the machine's speed and droplet volume functional diameter on the Christiansen uniformity coefficient (CU). Some tests with a water tin collector to determine water space distribution with a fixed sprinkler series in cultivated conditions have been done by Tarjuelo et al. (1999), and the results show that wind speed has a negative effect on uniformity of irrigation. The uniformity increases with jet-straightening vanes in the main nozzle. They also studied the sprinklers size and type, number of nozzles and jet-straightening vanes, pressure, rise height and irrigation range, and uniformity of irrigation by sprinklers with average size. Then they studied water distributed characteristics in different wind conditions. Deboer et al. (2001) measured droplets distributed for sprinklers with plate sprayers, by laser technology and the flour method. They concluded that both methods are comparable. The effect of nozzle shape and pressure on sprinkler characteristics by measurement of droplet size of sprinkler has been studied by Jiusheng (2002). He also studied (Jiusheng, 1996) sprinkler function governed by geometrical parameters of a square and triangular nozzle. Sourell et al. (2003) studied rotating spray plate sprinkler function and concluded that this type is effective in decreasing discharge and energy in irrigation systems. Kincaid (2005) studied a new kind of sprinkler that works on irrigation systems with a center pivot which is used on big farms in the USA. He introduced a method using computer software to predict the average and maximum discharge at every point of the center pivot movement. A new system of micro sprinklers to transfer water and fertilizer was designed by Coates et al. (2006). Silva (2006) studied the effect of spray energy sprinklers with different deviated plates on irrigation and sediment runoff.

MATERIALS AND METHODS

Various Sprinklers (Mechanism, Usage, and Sprinkler Quality)

Sprinklers for irrigation and home use are divided to 3 groups (www.sprinkler.com):

1. Bubblers.
2. Spray sprinklers.
3. Rotating sprinklers.

Sprinklers with different mechanisms, shapes and materials, are designed for special uses. The design of sprinklers prevents wasting water by irrigating a precise area. A lot of progress has been made in this connection. The superstand sprinkler is a good example.

Sprinkling height and surface covered are configurable. The sprinkler is made of zinc and brazen (Rowan et al., 2004). Figure 2 shows a superstand sprinkler. Figure 3 shows a shock sprinkler which has the ability to control the spray distance and density.

The lawn sprinkler robot operation can be scheduled and this sprinkler automatically provides needed water pressure. The other capabilities of this sprinkler include a remote control system. This sprinkler requires electricity and it is not useful in a place where electricity is not accessible.

THEORY EQUATIONS

The dominant equations of water droplet movement from the sprinkler outlet to the ground and also from sprinkler inlet to its outlet are considered here. Droplets traverse a projectile movement from outlet to ground and in this stage all projectile equations can be used for droplets. The following equations describe the stream line of droplets from inlet using the law of conservation of mass (continuity equation) and conservation of energy (Bernoulli equation) (Shames, 2003).

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+Z_2+\sum H_{loss}+\sum\frac{kV_2^2}{2g} \tag{3}$$

$$H_{Loss}=f\,\frac{L}{D}\frac{V_2^2}{2g} \tag{4}$$

Figure 2. Super stand sprinkler.

Figure 3. Shock sprinkler.

in which P is the pressure, V represents the mean velocity at levels z, H_{Loss} denotes length loss, and f is friction coefficient. In this equation subscript 1 is for sprinkler inlet and subscript 2 represents the outlet. P_2 is atmospheric pressure. Considering entrance pressure, V_2 can be estimated:

$$R_1 = \frac{V_2^2 Sin\, 2\varphi}{g} \tag{5}$$

$$H = \frac{V_2^2 Sin^2\, \varphi}{2g} \tag{6}$$

$$y = \frac{1}{2} gt^2 + V_2 tSin\, \varphi \tag{7}$$

in which R is the sprinkler's range, H represents the water apogee height, and y is the equation of water movement from levels Z_2 to earth. The calculated velocity from Equation 3 can be used in Equation 5. This range is not from the sprinkler outlet to ground, it is from the sprinkler outlet to water return (on stream line) to level Z_2. To determine the second part of the range, from a point on line Z_2 to earth, first of all, time of reaching water from Z_2 point to earth can be calculated by using Equation 7 and then it is replaced in the following equation:

$$R_2 = V_2 tCos\varphi \tag{8}$$

The final range is both range of the Equation 5 and 8. The top height can be obtained from the Equation 6. The requirement moment measure imported from water and air to sprinkler's rotator for rotating sprinkler on its own pivot, is calculated from the following equation:

$$T = -\frac{\omega\rho q l^2}{4} + \frac{\rho q^2 l}{4A_e}\cos(\alpha) \tag{9}$$

in which w is the angle speed of sprinkler, p represents sprinkler's density, l denotes distance of seesaw pivot to sprinkler's outlet, A is the outlet flow diameter, α represents the outlet angle from seesaw, and T is the necessary moment from sprinkler's rotation.

DESIGN SQUARE SPRAY SPRINKLER

Capability of CATIA software in sprinkler design

CATIA software does what CAD, CAE and CAM do. It means in addition to drawing different sections, it is useful in designing and building sections. To design this sprinkler, first of all different parts were designed in the "part Design" window and then these parts are assembled in the "assembly" window. With suitable care in "DMU Kinematics" window, and conditions, the sprinkler rotates in its own pivot. For sprinkler movement in "DMU Kinematics" window, existing forces and moments can also be defined. In this software, part materials can be defined and their weight can be estimated.

Existing Theories in Irrigation of Squared Surfaces

For irrigation of square surfaces, range must change continuously. The outfall angle must also change. To determine the change of outfall angle, we must calculate the change of outfall angle for different points with the rotation pivot. Letting the sprinkler angle against rotation pivot $\beta\varepsilon\ \theta$, and angle of sprinkler outfall Φ, having sprinkler range and considering sprinkler position as $\theta = 45^o$, $\phi = 45^o$, gives the maximum range. Then with triangle equations and $0 \leq \theta \leq 360$ the range amount is computed, f and having the range amount and projectile range, the amount of Φ in θ results.

Design of Square Spray Sprinkler

This sprinkler is designed such that the rotating force of the sprinkler must be the moment from the water spray and atmosphere. This force must overcome to sprinkler's weight and friction between different parts and friction between the follower and cam. When the sprinkler moves upon the cam surface, it must overcome forces from that part of sprinkler's weight upon the cam. It can be demonstrated that

$$F = mg \sin \beta \tag{10}$$

in which F is the weight force of considered part, m represents the mass of considered part, β denotes top and down angle of the tonsil relative to the horizon and g is gravity.

In down of cam weight force and rotation the force of sprinkler is added. So the sprinkler should be designed the way which the sprinkler rotation force is just a little bit more than weight force. Because in other situations, the follower speed on down cam surface may decrease a lot, up to there that follower only move upon top cam and comedown from down surface. To change sprinkler's outfall angle is done the same. A part behind the seesaw part considered as a follower which is hinged to seesaw part and the other side of that, is fixed on a cam which is designed earlier. Inlet of the sprinkler is considered such as the shock sprinkler, so with outfall changing, no change appears in the entrance position. A hexagonal spanner able part is fixed on the leg. At the end of entrance, an umbilical part is prepared to which a flexible tube is attached. The other end of the flexible tube is attached to the outlet umbilical. Water passes through the flexible tube and exits the nozzle outlet. After the outlet is fixed at the desired angle (the angle which is necessary to produce the moment for sprinkler rotation) the outlet must be fixed in this position using the screw that passes from seesaw and outlet. The cam size determines the range, outfall angle, sprinkler rotating angle. These factors are used in the written code.

Figure 4 shows the designed sprinkler using CATIA. By sprinkler rotation, friction appears between the entrance part and inside part of the spanner able section. To remove this problem, 5% is added between the spanner able part and the entrance. The required moment for rotating the nozzle is obtained using Equation 9 as follows:

l = 50.757 mm

$\alpha = 45°$

ρ = 980 kg/m^3

$\omega = V/l$ = 7.347/50.757 rad/s

$Ae = \pi d^2/4$, d= 4.5 mm

T = 1.38 N.m

The outlet velocity of sprinkler (V) is calculated by the Bernoulli equation considering all of the friction losses passing through the sprinkler. The outlet angle of the sprinkler toward the seesaw (α) is determined by placing the sprinkler at different angles until the required angle for sprinkler rotation is found.

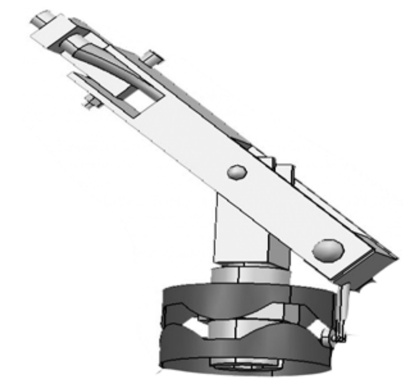

Figure 4. Schematic design with squared plane by CATIA.

PRODUCTION AND ASSEMBLAGE OF SQUARE SPRAY SPRINKLER

Choice of Material

To making the sprinkler lighter, low density materials were used. Materials are chosen that do not rust. From a study of different materials, Artelon was chosen. It has a density of about 980 kg/ m^3 and has a great resistance against chemical react. The cam aluminum was chosen. For the flexible tube, silicon hose is used. It is soft, smooth and has a high elasticity. For the spanner able part, brass is used. The legs are plastic.

Production and Assembling of Sprinkler

The entrance part which causes the nozzle to work properly is produced with a turning and milling progress. The entrance keeper parts and seesaw are completely produced by milling. To make the outlet part, the nozzle is produced by turning. In the next step the L shape part is produced by milling. Existing screws available on the market are used. The hexagon part is produced by turning and milling. Existing legs available on the market are used. To produce the cam, first the central hole and die inside is produced by turning. Then to make the top and down part of the tonsil, a wire cut machine is used. The designed sprinkler did not have any problems in production. To assemble the parts, the first cam is screwed on the spanner able part. Then a silicon hose placed on the entrance nozzle.

The hose is passed through the seesaw part, and the seesaw part placed on the entry keeper part. A screw passed through concentric holes of the seesaw and entry keeper. The other side of the hose is attached to the outlet nozzle. The outlet part is placed through the seesaw and a screw is passed through concentric holes of the seesaw and outlet and a nut is placed on the screw. Finally the outlet part is fixed with the said screw at the desired angle. Figure 5 shows the assembled sprinkler and Figure 6 shows the sprinkler at the moment of irrigation.

RESULTS AND DISCUSSION

Verification of Projectile Range Equation to Calculate Sprinklers Range

To understand if we can use the shot range equation for sprinkler range, an experiment was conducted. At a fixed pressure (example P = 1.2 bar), the shock sprinkler is tested and is photographed to show its function. The water spray path is measured by the real scale of range and top height, Figure 8. A diagram is drawn with the calculated points. Top height is obtained from Equation 11 for a specific projectile range (in a fixed area). A diagram is drawn and both are compared as shown in Figure 9. The results show that as an approximation the projectile range

Figure 5. Squared sprinklers.

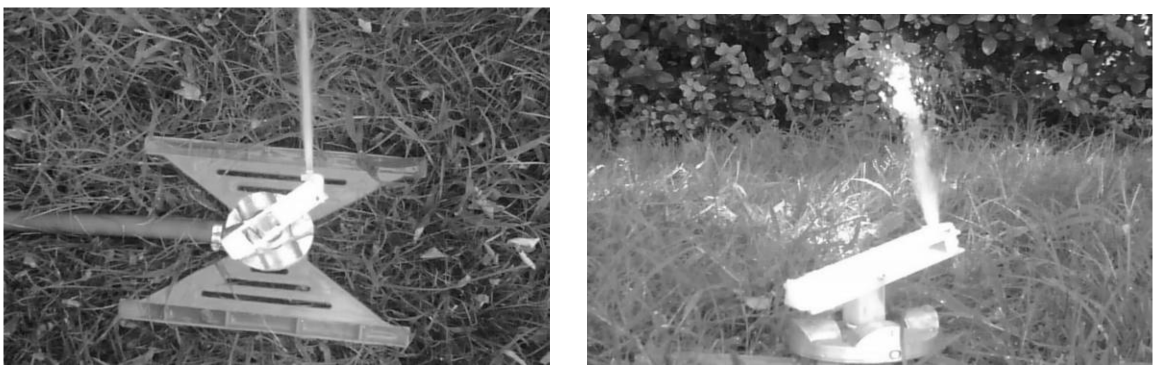

Figure 6. Made sprinkler doing irrigation.

equation can be used instead of sprinkler range. The difference between the two diagrams measure the facility mistakes for range and sprinkler height top and also the effect of air friction. In the equation air friction effects are not considered.

$$y = (\tan\theta_0)x - \frac{g}{2(v_0\cos\theta_0)^2}x^2 \tag{11}$$

Verification of Equation in Existing Sprinklers

Water drops move as a projectile away from the sprinkler outlet to the ground. Considering Figure 9, all equations describing the shot are correct for water drops in this stage. Waters mass is constant in the passing of water drops from inlet to outlet and knowing the law of conservation of mass and energy, the Bernoulli equation and continuity Equation 2 can be used to describe the process. To calculate *f* in the Bernoulli equation considering sprinkler type, the friction coefficient is included and *f* for every part is found (Shames, 2003). Using the Bernoulli equation and conservation of mass, and considering all losses in passing from sprinkler and applied pressure changes, the outlet velocity is calculated. Using the water throw angle, which is the sprinkler outfall angle, the range can be calculated. The dominant equations for two kinds of sprinkler are tested.

To calculate the required moment for sprinkler rotation on its own pivot the outlet velocity from sprinkler is used. It has two components. One is perpendicular in a seesaw direction and equals to $v\cos(\alpha)$. This component is suitable for sprinkler rotation. The required moment for sprinkler rotation includes moment which is produced and the moment from the atmosphere. The other component, the outlet velocity, equals to $\nu\sigma\iota\nu(\alpha)\ \omega\eta\iota\chi\eta$ changes the water like jet and determines the range. Comparing the empirical results to test results, it is possible to determine if the theoretical equations correctly predict the sprinkler behavior.

The Rotational Sprinkler

The rotational sprinkler is made from plastic. It is designed for a pressure of 1.5 bar, outlet angle 55º and range 3.3 m. Figure 7 shows this kind of sprinkler.

Various experiments with this sprinkler have been conducted. The results include range, highest point of sprinkler for inlet pressure and sprinkler entrance angle. The empirical (test) and calculated results are compared. When the calculated results and test results using required pressure for the rotational sprinkler are considered, effects of errors of measurement tools and air friction must be considered. Figure 8 shows the range of versus the input pressure for the rotational sprinkler.

Considering this graph, the experimental (EVP) result is above the calculated (CALC) diagram where pressure is lower than function pressure. The reason is that when water traverses a defined distance, water droplets move far apart and air friction is more effective. These processes reduce water velocity and make the range less than that calculated. The error between range test and calculated results for the plastic sprinkler as a function of pressure is as follows,

$$R_{c(P=1.5bar)} = 3.588m$$

$$Error\ percent = \frac{3.588-3.30}{3.30}*100 = \%8.72$$

The calculated error is confined satisfactorily.

Figure 9 shows sprinkler outfall angle effects on range. Considering this figure it is observed that a 45° angle has maximum range. For greater or lower values, range change is minor. For the rotational sprinkler with outfall angle 55°, range changes with angles 40°, 45°, 60° at a pressure of 1~2 bar.

In Figure 10 it can be seen that the sprinkler outfall angle affects the highest point. For the plastic sprinkler with outfall angle 55°, changes of the highest point are calculated for angles 40°, 45°, and 60° at a pressure of 1~2 bar. It can be seen that 60° has the highest point compared to others. The highest point increases from 0° to 90°.

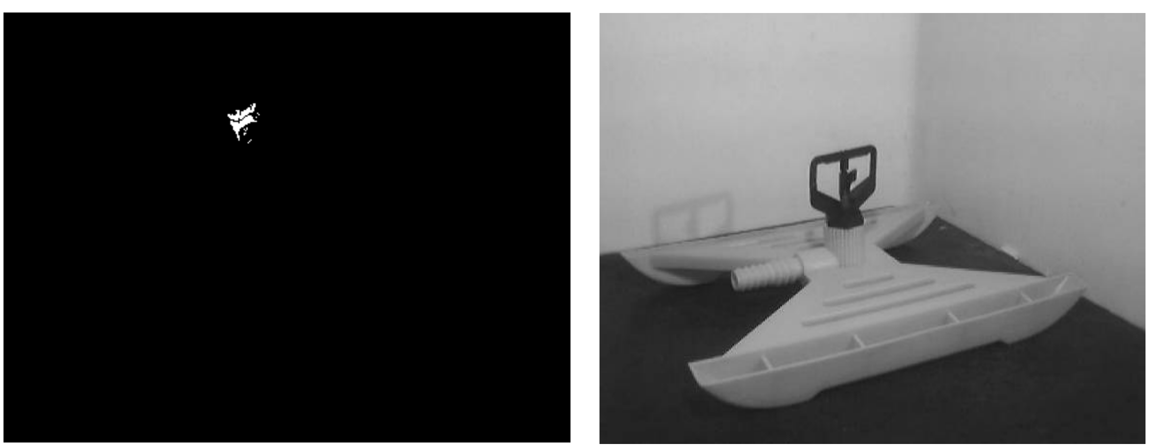

Figure 7. A kind of rotational sprinkler.

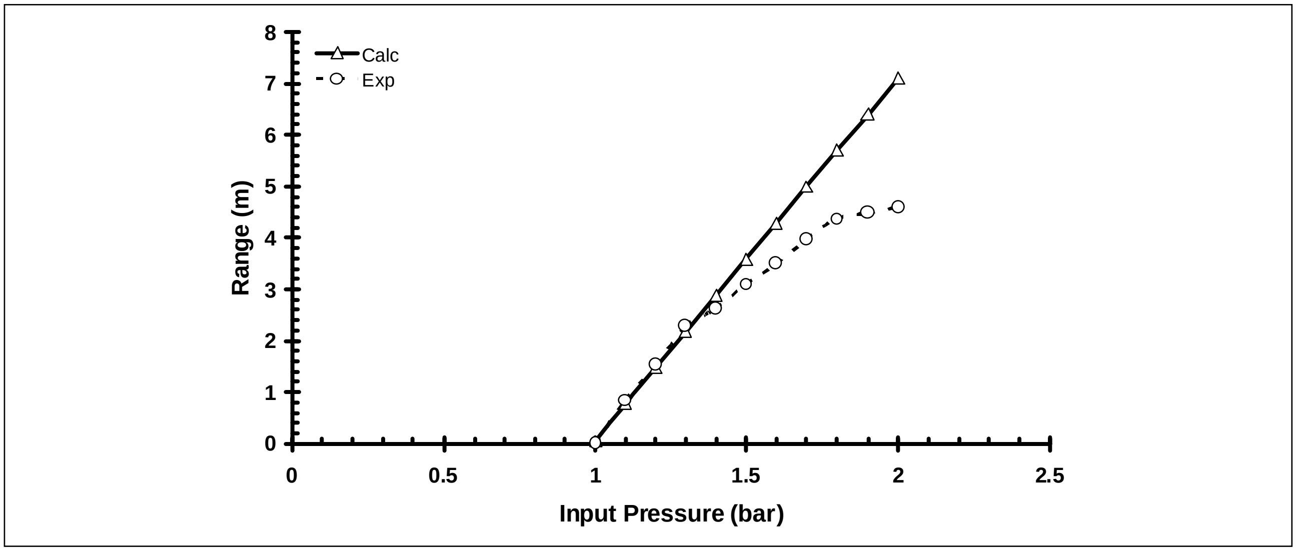

Figure 8. The range of sprinkler versus input pressure.

The Shock Sprinkler

The shock sprinkler is made from brass and it is designed for a pressure of 2.5 bar with outfall angle 30° and 10.2 m range. Figure 11 shows an picture of this type of sprinkler.

All test conducted on the rotating sprinklers were repeated on the shock sprinkler and the results were satisfactory.

Figure 12 shows the comparison between calculated results and the sprinkler test for the shock sprinkler. It can be seen that for pressures near the design pressure, the EXP diagram is higher than the CALC diagram, and for the design pressure, the calculated and experimental points almost match.

This means that there is no problem until design pressure and after design point with increasing input pressure, the distance of droplets from sprinkler is increased and considering Figure 1, droplet diameter and air friction effects are increased causing the real range be lower than the calculated one.

The error between the tested range and calculated results for the shock sprinkler as a function of pressure is as follows:

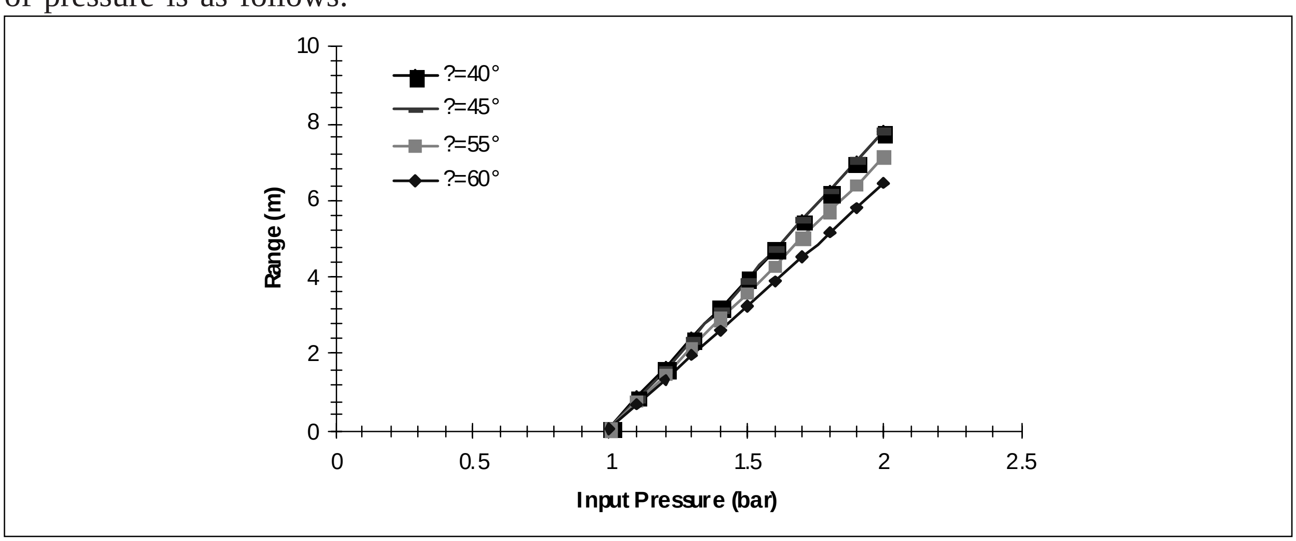

Figure 9. Sprinkler outfall angle effects on range.

$$R_{c(P=2.5bar)} = 10.361m$$

$$Error\ percent = \frac{10.361 - 10.2}{10.2} * 100 = \%1.6$$

The calculated error is confined satisfactorily

For the shock sprinkler with outfall angle of 30°, changes of range are calculated for angles 25°, 40°, 45° at pressures of 1~2.5 bar. In Figure 13 it can be seen that 45° has the maximum range. For higher or lower values range change is minor.

In Figure 14 the effects of sprinkler outfall angle on the highest point for the shock sprinkler is shown. Changes of the highest point for angles of 25°, 40°, and 45° and pressures of 1~2 bar are calculated. It can be seen that 45° gives the maximum highest point. The range for upper angles gives a higher highest point and for lower angles gives a lower highest point.

Survey Squared Spray Sprinkler

At first, the irrigated surface with this sprinkler was not quite square. The sides of the square were bowed into the square and the angles of the square became too rounded. The problems in the square surface were due to the difference of sprinkler outfall angle between cams up and down, which was more than expected. These problems were solved by reducing the height of top of cam and tonsil leg. After resolving these problems, through survey and multiple experiments on the

Figure 11. A schematic from shock sprinkler.

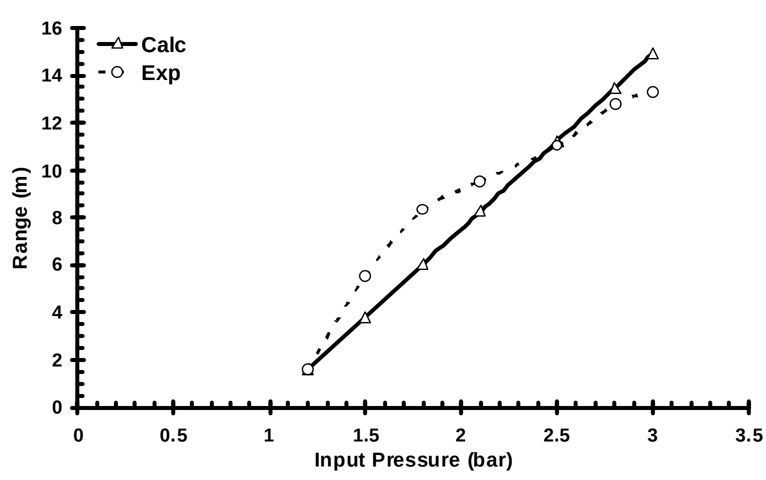

Figure 12. The range of shock sprinkler versus input pressure.

square spray sprinkler, it was shown that the irrigated surface by this sprinkler is close to the desired surface configuration.

Figure 15 shows a square spray sprinkler irrigating a square with length 3.5 m and pressure 1.5 bar. The right part of the figure shows the surface at the beginning of irrigation and the left shows the surface after some minutes after irrigation. It can be seen that the angles of the irrigated surface are a little rounded instead of being sharp. The reason is the tonsil leg surface (a place where follower is on its lower position). Whenever the cam leg surface gets decreased, the angles of the irrigated square are sharper. Considering the limitations of the sprinkler construction, the possibility did not exist to make the tonsil leg surface smaller. The sprinkler tested in working pressure and irrigated square surface was found with the desired dimension.

In reality the design pressure is always less than the calculated one and the reason is the effect of air friction on separated droplets. The difference between the defined range and the calculated results is the error of calculating down falls through the sprinkler, its matches and joints, and measurement instrument errors for sprinkler range length and air friction effects.

As the sprinkler range increases, the distance between output droplets increases, and because of increasing surfaces between water molecules with air, air friction effects on spray droplets increases and the difference between the calculated and real range increases. For this reason, the position of top height in sprinklers is not exactly in the center of the middle distance of the exit

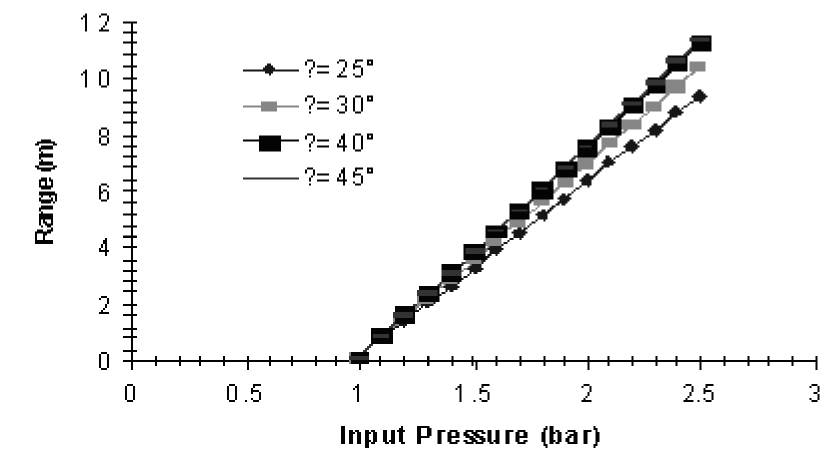

Figure 13. Shock sprinkler outfall angle effects on range.

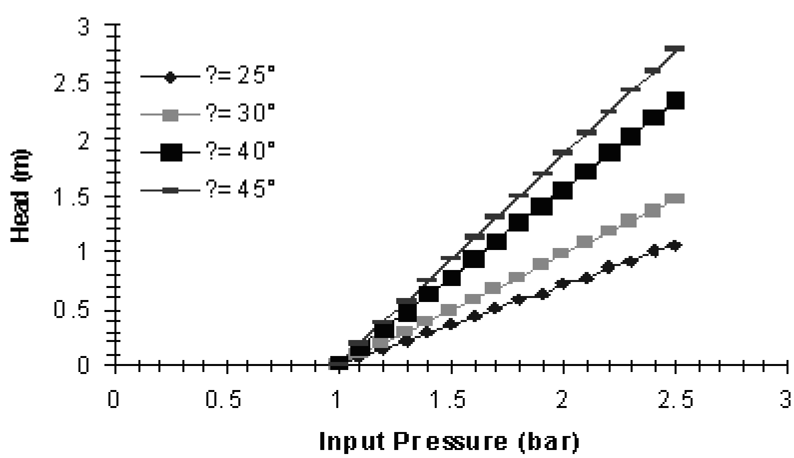

Figure 14. Shock sprinkler outfall angle effects on head.

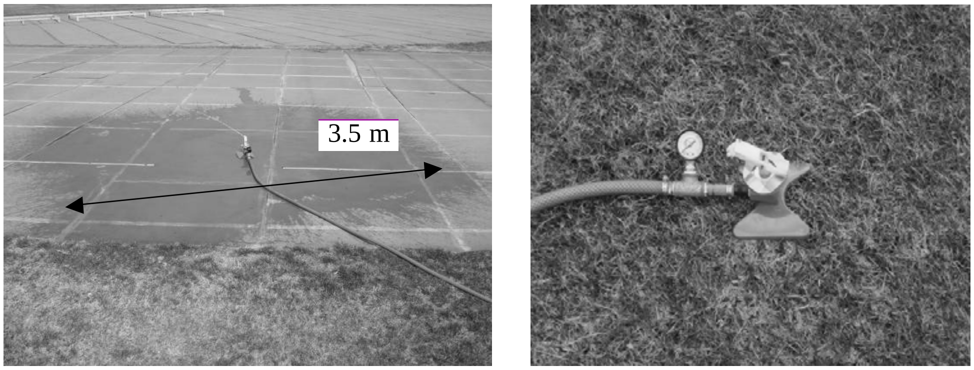

Figure 15. Quality of squared sprinkler application.

point from sprinkler and the range point of the sprinkler. It is in a point closer to the range point of the sprinkler. To have a suitable moment value from water and atmosphere, the outlet nozzle part must have a suitable angle. In other words (in smaller or greater angles than this value), we do not have a suitable moment and so the sprinkler cannot rotate on its own pivot. The suitable exit part angle depends on sprinkler characteristics such as sprinkler entrance diameter, changes of diameter from inlet to outlet, and the water angle movement measurement on exit from the outlet.

Every kind of sprinkler with any kind of mechanism, if the outfall angle is 45°, has the maximum range. With increasing entrance pressure, the sprinkler range and highest point is increased and with increasing outfall angle, the highest point is also increased. The necessary angle change value of the sprinkler outfall in irrigation of a square surface for every kind of sprinkler with any kind of mechanism must be from 22.5° to 45° angles.

ACKNOWLEDGMENTS

The authors would like to thank Dr. H. Golmahi, Associate Prof., University of Sari, and Dr. I. Shooshpasha, Assistant Prof., University of Mazandaran, for in depth review and giving permission to publish this paper.

REFERENCES

Al-Jamal, M.S., S. Ball, and T.W. Sammis. 2001. Comparison of sprinkler, trickle and furrow irrigation efficiencies for onion production. Agricultural Water Management V.46, PP. 264-266.

Coates, R.W., M.J. Delwiche, and P.H. Brown. 2006. Design of a System for Individual Microsprinkler Control. Transaction of the American Society of Agricultural and Biological Engineers. V.46 (9), pp. 1963-1970.

DeBoer, D. W., M.J. Monnens, and D.C. Kincaid. 2001. Measurement of Sprinkler Droplet Size. Applied Engineering in Agriculture. V.17 (1), pp. 11-15.

Hills, D.J., and J. Barragan. 1998. Application uniformity for fixed and rotating spray plate sprinklers. American Society of Agricultural and Biological Engineers. V.14 (1), pp. 33-36

Jiusheng, Li. 1996. Sprinkler Performance as function of nozzle geometrical parameters . Journal of Irrigation and Drainage Engineering. ASCE. V.122 (4), pp. 244-247.

Jiusheng, Li. 2002. Effect of pressure and nozzle shape on the Characteristics of sprinkler. AGRIS. V.66 (1), pp. 15-21.

Kang, Y., Q.C. Wang, and H.J. Liu. 2005. Winter wheat canopy interception and its influence factors under sprinkler irrigation. Agricultural Water Management. V.74, pp. 192-199.

Kincaid, D.C. 2005. Application rates from center pivot irrigation with current sprinkler types. Applied Engineering in Agriculture. American Society of Agricultural and Biological Engineers. V.21 (4), pp. 605-610.

Rowan, M., K. Mancl, and H. Caldwell. 2004. On-site Sprinkler Irrigation of Treated Wastewater in Ohio. The Ohio State University Extension. Sec 1-12.

Shames, I.H. 2003. Mechanics of Fluids. 4th ed., McGraw Hill Book Co. New York.

Silva, L.L. 2006. Effect of spray head sprinklers with different deflector plates on irrigation uniformity, runoff and sediment yield in a Mediterranean soil. Agricultural Water Management. V.85 (3), pp. 243-252.

Sourell, H., J.M. Faci, and E. Playan. 2003. Performance of rotating spray plate sprinklers in indoor experiments. Journal of Irrigation and Drainage Engineering. ASCE. V.129 (5), pp. 376-380.

Sudheer, K.P., and R.K. Panda. 2000. Digital image processing for determining drop sizes from irrigation spray nozzles. Agricultural Water Management. V.45, pp. 159-167.

Tarjuelo, J.M., J. Montero, P.A. Carriln, F.T. Honrubia, and M.A. Calvo. 1999. Irrigation Uniformity with Medium Size Sprinklers Part II. American Society of Agricultural Engineers. V.42 (3), pp. 677-690.

www.sprinkler.com

ADDRESS FOR CORRESPONDENCE
Janali Taghavi
Department of Irrigation,College of Agricultural Engineering
University of Sari
PO Box 578
Sari, Iran

Email: taghavij@yahoo.com