DISSERTATION

SMART SPRINKLER: VARIABLE WATER FLOW USING NOZZLE SIZE CONTROL TO IMPROVE UNIFORMITY

By

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14830

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION

CERTIFICATION OF APPROVAL

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ABSTRACT

Irrigation is essential in some places to perform uniform distribution of irrigation. As observed from previous literature and personal observation, some rotating head sprinklers cannot perform uniform water distribution. The target area of irrigation will not be able to achieve optimum water distribution. This project attempts to improve water distribution per unit area of rotating sprinkler, save water and it will improve irrigation of water to be more efficient. In order to achieve these, the author has taken initiative to design a smart sprinkler by introducing a combination of sprinkler turbine with nozzle flow control. Fabrication and testing is done to measure the water distribution to be compared with the original one. From the test result, the water distribution per unit area of Smart Sprinkler is found to be 13.419 ml/m^2 while 12.191 ml/m^2 for original model. As a conclusion, Smart Sprinkler has been able to increase the volume of water per unit area by 1.228 ml/m^2 (10%).

ACKNOWLEDGMENT

First and foremost, the author would like to thank the Almighty, Allah SWT for His guidance and blessings throughout his training period, needless to say throughout his whole life. Without His permission, the author would not be able to finish his training and embark on the journey of life.

Secondly, the author would like express his deepest gratitude to his supervisor, Ir Dr Hamdan Haji Ya, for his guidance and supervision throughout the project. Without his help, the author believe this project will not be a success. Through discussions with him, the author has been able to further explore and develop the concept of smart sprinkler.

Thirdly, the author would like to thank all lab technicians who have sacrificed their time and effort during the process of fabrication. Without their expertise and knowledge in manufacturing, the author will face difficulties in producing specifications of the prototype.

Finally, thousands appreciation to family especially his mother for all the advice and moral support given throughout the period of 8 months. She has been tirelessly giving support to the author to strive through challenges faced throughout the project

Not to forget, friends who have helped and supported the author, through manpower and emotional support. The author would like to specifically mention their names in this acknowledgment.

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CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1. Irrigation System

Irrigation is essential in some places in order to grow crops, particularly arid areas. In general, there are various methods of irrigation techniques, depending on how the water is distributed within the field. Types of methods commonly used are surface irrigation (furrow, border, basin), sprinkler irrigation (periodic-move, solid-set, continuous-move), and micro irrigation (micro sprinkler, drip emitters, and drip tape) (Hanson, 2005). These methods are operating with one goal in common; to supply and perform uniform water distribution across the field. Table 1 shows the characteristics for each type of irrigation (Irrigation).

Table 1 Irrigation techniques and their characteristics

Irrigation Technique	Characteristic
Surface Irrigation	-water moves over and across the land by simple gravity flow in order to wet it and to infiltrate into the soil. Also called as flood irrigation
Localized Irrigation	-water is distributed under low pressure through a piped network, in a predetermined pattern, and applied as a small discharge to each plant or adjacent to it.
Drip Irrigation	-also known as trickle irrigation - Water is delivered at or near the root zone of plants, drop by drop.
Sprinkler Irrigation	-water is piped to one or more central locations within the field and distributed by overhead high-pressure sprinklers or guns.
Sub-irrigation	-sometimes called seepage irrigation - method of artificially raising the water table to allow the soil to be moistened from below the plants' root zone

According to Sharma & Sharma (2007), the efficiency of an irrigation method depends on:

- Topographic condition of the land
- Characteristics of the soil
- Underground water zone
- Soil salinity
- Crop rotation

1.1.2. Sprinkler Irrigation Method

Major parts that make up a sprinkler system are pipes with sprinklers or nozzles for water distribution. The discharged water is required to be at high velocity to reach a certain range of crops. This requires the system to be operating under pressure, which can be provided by the Earth gravity or a pump.

In terms of uniformity, sprinkler system depends primarily on the ability of the system to apply equal amounts to all the designated areas. One of the methods to measure the uniformity is the "Catch Can" experiment. In this experiment, cups will be arranged according to guidelines provided in standard testing according to ANSI/ASAE S436.1 DEC01. The sprinkler package will be installed and adjusted up to the design specifications. The desired test pressure is then specified and it should be maintained throughout the test. The result will be interpreted through the amount of water collected from the cups after the sprinkler has been activated.

Depending upon the method of water distribution, sprinkler systems can be further classified. There are stationary, semi-portable and portable sprinkler systems available in the market. Rotating sprinklers, fixed heads or nozzle lines are the means of water distribution for stationary systems (Christiansen, 1942). This method is the most commonly used by homeowner. It is also noticed that in UTP compound, rotating sprinkler stationary system is used to perform irrigation of lawn and plants.

1.1.3. Rotating Sprinkler System

Rotating sprinklers have capacities of 1 to more than 100 gallons per minute. Some of the larger sprinklers are designed for pressures of 60 to 100 psi, and will cover circles up to approximately 200 feet in diameter, whereas some of the small ones will operate on pressures of 10 pounds per square inch or less (Christiansen, 1942). Two types of rotating sprinklers are the whirling sprinkler and slow-revolving sprinkler. The main difference between these two is the rotating speed; whirling sprinkler rotates at a faster rate while slow-revolving sprinkler rotates at 1-2 revolution per minute (Christiansen, 1942). This leads to the fact that slow-revolving sprinkler can cover a greater distance compared to the whirling sprinkler when operating under the same pressure. More coverage equals less sprinkler positioning as it can be spaced out more.

Christiansen (1942) noted that there are various designs of rotating sprinkler heads. Figure 1 shows some the rotating sprinkler heads.

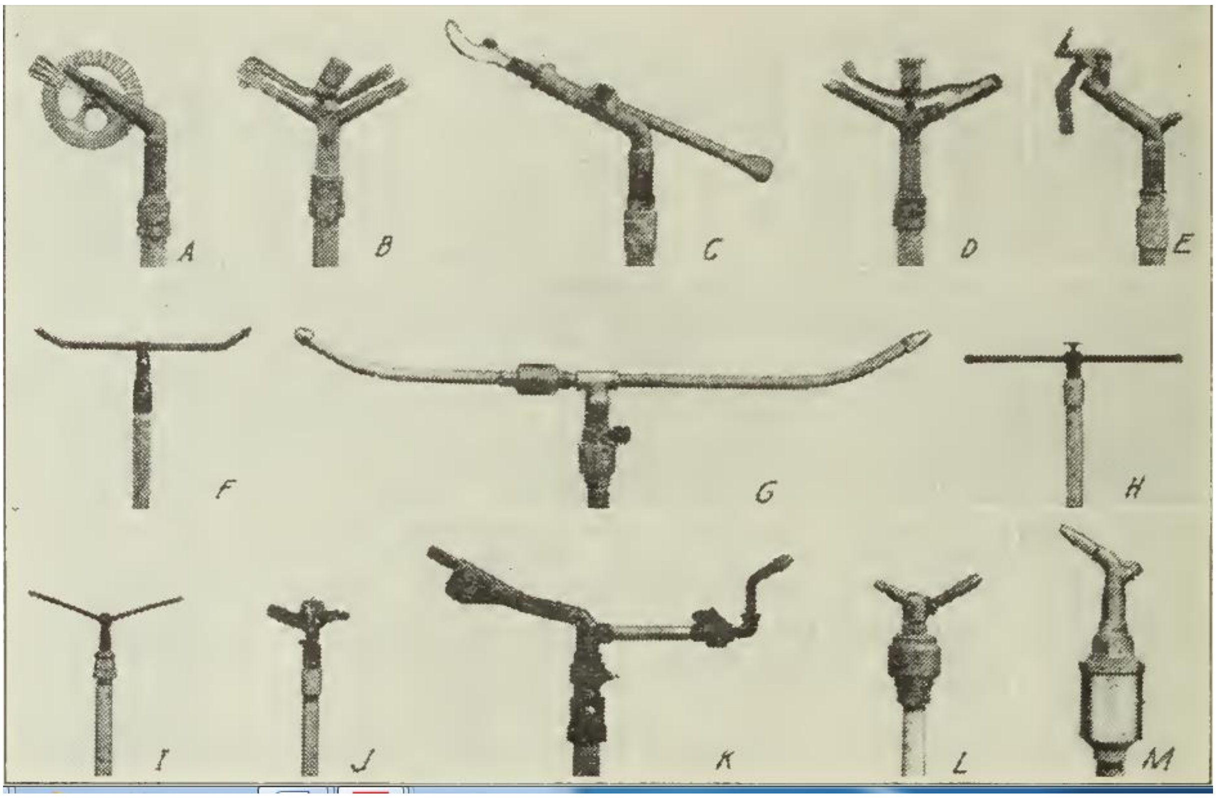


Figure 1 Rotating sprinkler heads

1.2. Problem Statement

It is noticed that conventional sprinkler designs have one common flaw, inability to perform uniform water distribution from one strip to another. This problem is observed visually by the author in Universiti Teknologi PETRONAS (UTP). The most visible one is in Oval Park and recreational park in UTP. It was observed that the distribution pattern is as shown in Figure 2. The outermost strip is usually well-watered while the region in between up to the sprinkler receive inadequate amount of water.

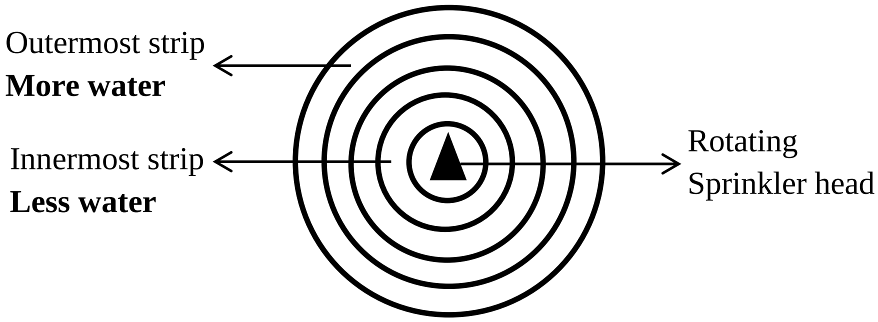


Figure 2 Sprinkler water distribution pattern

This non-uniform distribution will create differences between the plants within the sprinkler range. Area with sufficient water will grow healthy, while the area with insufficient of it will show less growth.

1.3. Objective and Scope of Study

The main purposes of this project are:

1. to study the principle of nozzle and its effect in terms of flow,
2. to design and introduce improvement to conventional sprinkler design using nozzle flow control in order to improve uniformity of water distribution.

Within 8 months, the author will perform studies on irrigation, particularly rotating head sprinkler and nozzle. Selection of preliminary sprinkler design and simulation will be carried out. In simulation, test and analysis are expected to be performed. Once completed, detailed drawing followed by model will be produced. The test run, result collection and analysis are expected to be performed afterwards.

CHAPTER 2

LITERATURE REVIEW

2.1 Sprinkler Turbine

A rotating sprinkler system can rotate due to centrifugal forces produced by water exiting the nozzle at the end of the sprinkler head. This turbine can be termed as "split reaction water turbine" (Date & Akbarzadeh, 2010). The conceptual split reaction water turbine is shown in Figure 3. Operationally, pressurized water enters the water chamber and exits the nozzles tangentially with high velocity thus creating torque.

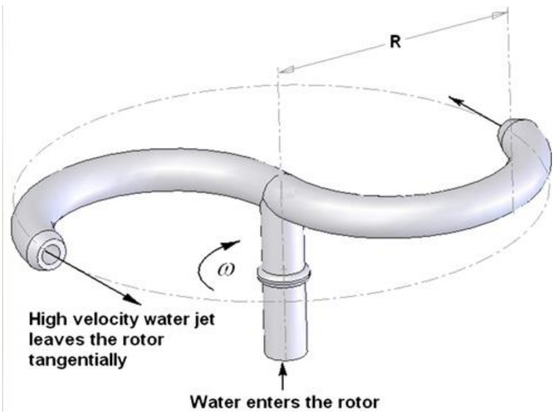


Figure 3 Simple reaction turbine

Basically, rotating sprinklers convert static head available in the water to dynamic head with the converging nozzles.

Nomenclature

A =total nozzle exit area (m2)

d_n =nozzle diameter (m)

D_{opt} =optimum turbine diameter (m)

g =acceleration due to gravity (m/s2)

h =height of the rotor/nozzle (m)

H =head (m)

H_c =centrifugal head (m)

k =factor for viscous losses

m =mass flow rate of water through the turbine (kg/s)

R =radius of the turbine (m)

R =opt optimum turbine radius (m)

t =turbine wall thickness (mm)

T= torque (N-m)

U =tangential velocity of the nozzles (m/s)

V_a =absolute velocity of water (m/s)

V_r =relative velocity of water (m/s)

W = output power (W)

u =angular speed of the rotor (radian/s)

r =density of water (kg/m3)

h =turbine efficiency

SRT =split reaction turbine

Assuming water to be incompressible,

$$U = R\omega \quad (1)$$

$$V_a = V_r - U \quad (2)$$

Mass flow rate from nozzle,

$$\dot{m} = \rho V_r A \quad (3)$$

And applying conservation of momentum, assuming no angular momentum of the inlet flow, gives

$$T = \dot{m} V_a R \quad (4)$$

2.2 Flow Control using Nozzle

Nozzle has been used to control flow in various applications. Its working principle is adapted from the **Bernoulli's principle**. Water from the inside chamber of a sprinkler will flow through the reduced diameter of the nozzle. Bernoulli's principle can also be derived directly from Newton's 2nd law. Figure 4 shows the application of Bernoulli's principle in nozzle of reduced diameter, from $d_n = 2$ to $d_n = 1$. The flow rate is equivalent at all points (Point 1 and 2) in the nozzle, $Q = A_1V_1 = A_2V_2$. Bernoulli's equation gives pressure at Point 2 as

$$p_2 = p_1 + \frac{\rho}{2}({v_1}^2 - {v_2}^2) \qquad (5)$$

where is the gauge pressure at Point 1, is the density of working fluid, is the pressure at Point 2,is the velocity of fluid at Point 1 and is the velocity of fluid at Point 2.

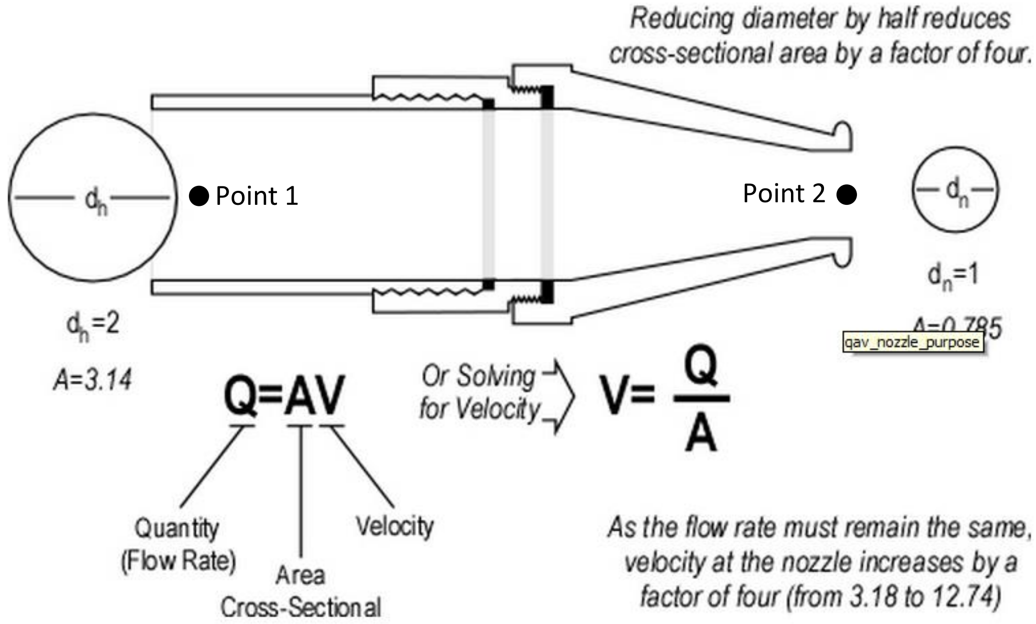


Figure 4 Nozzle with reduced diameter

2.3 Christiansen's Coefficient of Uniformity

Christiansen's coefficient of uniformity is a tool to evaluate performance of a sprinkler based on the uniformity of water distribution in percentage (Christiansen, 1942). It takes into account the depth of measured water in total container and overall measured depth of water (Christiansen, 1942). Two of the most frequently used technique to quantify uniformity through CU are rain gauge and "catch can" experiment ("Irrigation Equipment", 1990). According to Tarjuelo et al. (1999), the formula for Christiansen's coefficient of uniformity is given as

$$\text{CU} = \left(1 - \frac{\sum_{i=1}^{n}|x_1 - \bar{x}|}{nx}\right) * 100 \qquad (6)$$

Where is the individual depth of catch observations from uniformity test (mm), is the average water depth (mm) collected in all cans and n is the number of observations (Tarjuelo, Montero, Honrubia, Ortiz, & Ortega, 1999).

Sourell, Faci, & Playán (2003) interpretation of CU values are shown in Table 2.

Table 2 Level of uniformity corresponding to CU value

Cu Value Range (%)	Level Of Uniformity
< 65	Inadequate
65-75	Stable
75-85	Average
> 85	Good

CHAPTER 3

METHODOLOGY

3.1 Process Flow

Figure 5 shows the steps that will be performed during project execution.

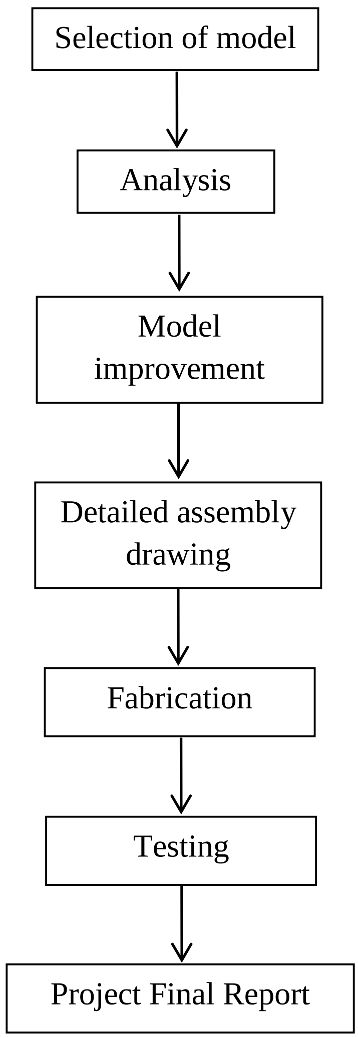


Figure 5 Steps or work sequence of project execution

3.2 Selection of Model

Various models of sprinkler and nozzle flow control will be reviewed based on the distance covered, speed of rotation and required optimal operating pressure. The sprinkler and nozzle will be coupled together in order to incorporate nozzle flow control.

3.3 Analysis

Analysis using theories, formulae and related principles is done.

3.3.1 Pressure-Discharge Relationship

$$q = K_d\sqrt{P} \quad (7)$$

Where q is the flow rate; K_d is the empirical coefficient and P is the pressure.

The above equation is applicable to a simple round orifice nozzle and is derived from Bernoulli's equation:

$$\frac{P}{\gamma} = \frac{V^2}{2g} = \frac{q^2}{2gA^2} \quad (8)$$

$$\sqrt{\frac{2gPA^2}{\rho g}} = K_d\sqrt{P} = q \quad (9)$$

Assuming the elevations are the same ($z_1 = z_2$) and the conversion through the nozzle is assumed to be all pressure to all velocity. Equation q is accurate for a certain pressure range.

K_d can also be separated into an orifice coefficient, K_o, and nozzle bore area, A.

$$q = K_o A\sqrt{P} \quad (10)$$

$$K_o = \sqrt{\frac{2}{\rho}} \quad (11)$$

Nozzle diameter can be determined by rearranging the above equation:

$$d = \sqrt{\frac{4q}{K_o\pi\sqrt{P}}} \quad (12)$$

3.3.2 Sprinkler Distance and Trajectory Estimation

The trajectory is to be estimated using motion equation but not considering the aerodynamic resistance and wind effect. Plus, it is only applicable to the largest drops from the sprinkler operating under recommended condition.

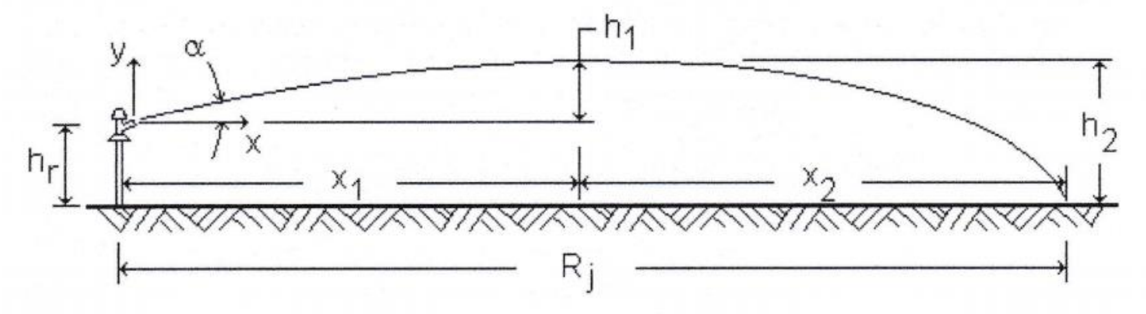


Figure 6 Water trajectory

If the velocity in the vertical direction at the nozzle, V_y is taken as zero at time t_1, then,

$$\left(V_{y_{t1}}\right) = V_0 \sin\alpha - gt_1 = 0 \qquad (13)$$

Where V_0 is the velocity of the water stream leaving the nozzle (m/s); α is the angle of the nozzle; t_1 is the time for a drop to travel to the highest point in the trajectory (s); and g is the ratio of weight to mass (9.81 m/s^2).

The above equation can be solved for t_1 and the initial V_0 can be calculated based on the sprinkler discharge and nozzle diameter. Value of α can be found from manufacturers' information.

To solve for t_1:

$$t_1 = \frac{V_0 \sin\alpha}{g} \qquad (14)$$

Substituting t_1 into

$$h_1 = V_0 \sin\alpha \, t_1 - \frac{g{t_1}^2}{2} \qquad (15)$$

Yielding

$$h_1 = \frac{\sin\alpha^2 {V_0}^2}{2g} \qquad (16)$$

For horizontal direction, assume no horizontal acceleration:

$$x_1 = V_0 \cos \alpha \, t_1 \tag{17}$$

Solving for h_2,

$$h_2 = h_r + h_1 = V_y t_2 + g{t_2}^2/2 \tag{18}$$

Where h_r is the riser height (m); t_2 is the time for a drop of water to travel from the highest point of trajectory to the ground; and $V_y = 0$.

Then, x_2 is defined as,

$$x_2 = V_0 \cos \alpha \, t_2 = \sqrt{\frac{2(h_r + h_1)}{g}} \tag{19}$$

Therefore, the approximate wetted radius is

$$R_j = x_1 + x_2 \tag{20}$$

In summary, if the effect of wind and air resistance is ignored, the R_j is a function of

a. Angle, α
b. Nozzle velocity, $\frac{q_a}{A}$
c. Riser Height, h_r

3.3.3 Irrigation Distribution

After testing is done, the theoretical and experimental volume of water per unit area is calculated. The volume of water is derived from the flow rate of the main nozzle. Knowing the flow rate in ml per second, the volume of water spouted in 1 second can be calculated by multiplying flow rate with 1 second.

$$Volume\ of\ water\ in\ 1\ second = flow\ rate\ x\ 1\ second \tag{21}$$

For the area, it is calculated using the rate of rotation and angle covered in 1 second and radius of the wetted area. Using rotation per minute, rpm, rate of rotation per second is find by dividing rpm with 60 seconds.

$$rps = \frac{rpm}{60\ s} \tag{22}$$

From rps, the angle of wetted area covered in 1 second is calculated.

$$angle\ of\ wetted\ area\ in\ 1\ s\ in\ radian = rps\ x\ \frac{\pi}{180°} \tag{23}$$

Using the formula of area of sector, the area of wetted area in 1 second is calculated.

$$A = (\frac{\theta}{2}\ x\ r^2)\ m^2 \tag{24}$$

Using volume of water in 1 second and area, the volume of water per unit area can be calculated.

$$\text{volume of water per unit area} = \frac{Volume\ of\ water\ in\ 1\ second}{A}\ ml/m^2 \tag{25}$$

For experimental value, the volume of water per unit can also be calculated using the same formulae but by using data of volume of water obtained during experiment.

3.3.4 Flow in Irrigation System and Sprinkler

The water stream move from one point to another in a sprinkler system. In order to know this, the knowledge of the total sprinkler system for UTP is required. Referring to UTP compound, there are more than 100 sprinklers which receive water from main pump located near to football field. This pump receive water from the lake and boost it to 8-10 bar for irrigation purpose. Once distributed across UTP, the water pressure will decreases. Figure 7 shows the simplified schematic diagram for UTP irrigation system.

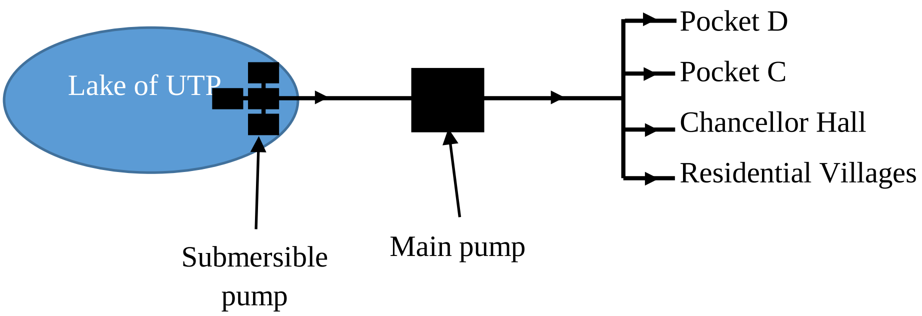


Figure 7 Schematic of UTP irrigation system

From the main pump, water will be distributed across sprinklers around UTP. There are a few type of sprinklers used in UTP but the focus of this project will be on the rotating head sprinkler. Water from pump will enter the sprinkler and be further separated into 2 streams, main and secondary streams. Figure 8 shows the main and secondary nozzle/outlet for water streams.

Figure 8 Main and secondary nozzle of sprinkler gun

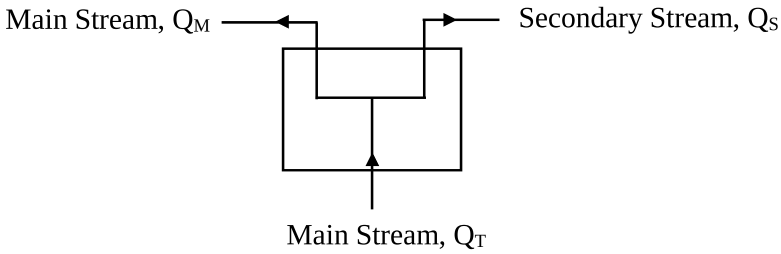


Figure 9 Schematic diagram of water flow in sprinkler gun

From the schematic diagram above, the main flow rate can be calculated as:

$$Q_T = Q_M + Q_S \tag{26}$$

From Bernoulli's equation,

$$Q = AV \tag{27}$$

Therefore,

$$A_T V_T = A_M V_M + A_S V_S \tag{28}$$

Smart Sprinkler with its improved design will revise the schematic to become as shown in Figure 10.

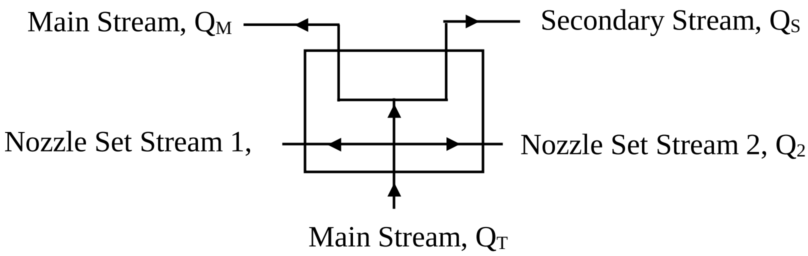


Figure 10 Smart Sprinkler schematic diagram

The design of Smart Sprinkler introduces sets of nozzle with different sizes. Therefore, the formula of flow will become:

$$Q_T = Q_M + Q_S + Q_1 + Q_2 \tag{29}$$

And

$$A_T V_T = A_M V_M + A_S V_S + A_1 V_1 + A_2 V_2 \tag{30}$$

3.3.5 Force Analysis of Sprinkler Rotation

The rotation of the sprinkler is initiated through mechanical means. Water stream from the main nozzle hit the paddle on the curved part. This will redirect the water to the next curved section of the paddle. Force analysis is done for every point hit by water stream.

Figure 11 shows the sprinkler gun with labeled points of force analysis.

Figure 11 Point 1 at sprinkler

For point one, the angle of which water stream come is assumed to be zero, horizontal and parallel to the ground. Upon hitting the curved part of point 1, reaction force, F_A is created and the combination of the forces produce resultant force, F_R. Figure 12 shows the point force analysis as a free body.

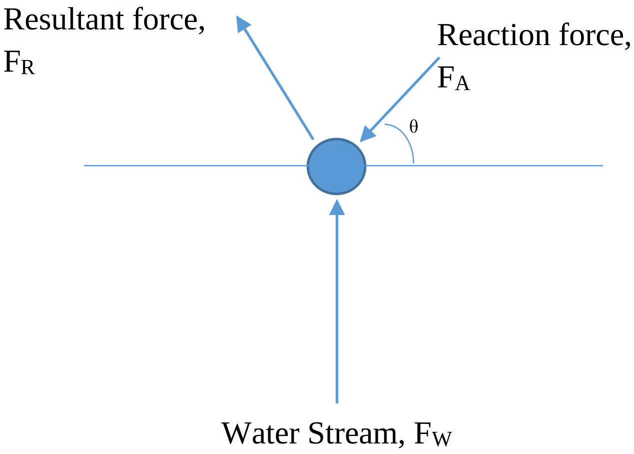


Figure 12 Point 1 force vectors analysis

The force triangle of Point 1 is shown in Figure 13.

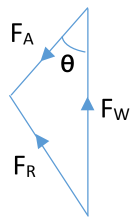


Figure 13 Force triangle at Point 1

Analysis for F_R in x and y direction is shown below.

$$F_{R,x} = F_A \cos\theta \tag{31}$$

$$F_{R,y} = F_W - F_A \sin\theta \tag{32}$$

$$\therefore F_R = \sqrt{(F_A \cos\theta)^2 + (F_W - F_A \sin\theta)^2} \tag{33}$$

Next, analysis at point 2 is done. Figure 14 shows Point 2 of the sprinkler model.

Figure 14 Point 2

The resultant force, F_R from point one will continue to travel and hit point 2 at an angle of θ. Figure 15 shows the force vectors available at Point 2.

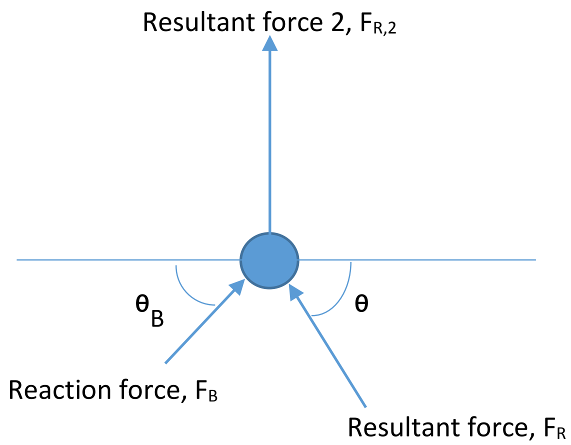


Figure 15 Force vectors at Point 2

Therefore, the force vector triangle will become

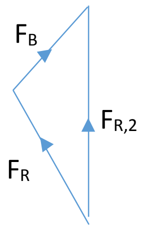


Figure 16 Force vectors triangle at Point 2

Analysis for $F_{R,2}$ in x and y direction is shown below.

$$F_{R,2,x} = F_B \cos \theta_B - F_R \cos \theta \quad (34)$$

$$F_{R,2,y} = F_B \sin \theta_B + F_R \sin \theta \quad (35)$$

$$F_{R,2} = \sqrt{(F_B \cos \theta_B - F_R \cos \theta)^2 + (F_B \sin \theta_B + F_R \sin \theta)^2} \quad (36)$$

However, the force that rotates the paddle is actually $F_R \cos \theta$. The force and distance that produce moment about Point 3 is shown in Figure 17.

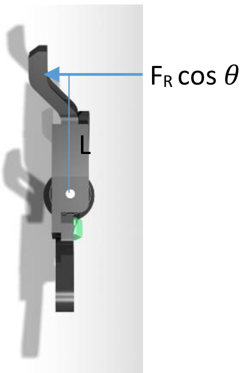


Figure 17 Moment caused by force and distance

$$M_3 = F_R \cos \theta \, x \, L \quad (37)$$

This will cause the paddle to rotate about Point 3 for a range of θ. F_W is actually a function of θ. As the paddle moves, the portion of water that hit point 1 reduces proportionally with θ. As F_W becomes zero, $F_R \cos \theta$ also becomes zero and the rotation of paddle stops. The spring torsion will overcome the moment and forcer the paddle to return to its original position. Upon collision, momentum of the paddle forces the main body of sprinkler gun to rotate and this cycle continues.

3.4 Model Improvement

Improvement will be made to the selected preliminary model in order to achieve optimal condition for the flow, coverage and uniformity.

Upon selection of best preliminary model, nozzle incorporation with sprinkler turbine is modeled. 2 parts, inner and outer, is modified with the addition of nozzles. Figure 18 shows the original model of selected sprinkler gun.

Figure 18 Original design of sprinkler gun

Once partially disassembled, the original model will be consisting of 3 major parts which are the main, inner and outer parts, shown in Figure 19, 20 and 21.

Figure 19 Main part of sprinkler gun

Figure 20 Inner part of sprinkler gun

Figure 21 Outer part of sprinkler gun

The modification is done to the inner and outer part. The author increases the length and introduces nozzles to both parts. On the inside, the author incorporates 3 set of nozzles consisting of 5 nozzles in 1 set arranged vertically with 5 mm vertical offset and 120^0 offset from 1 set to another. This modification is shown in Figure 22.

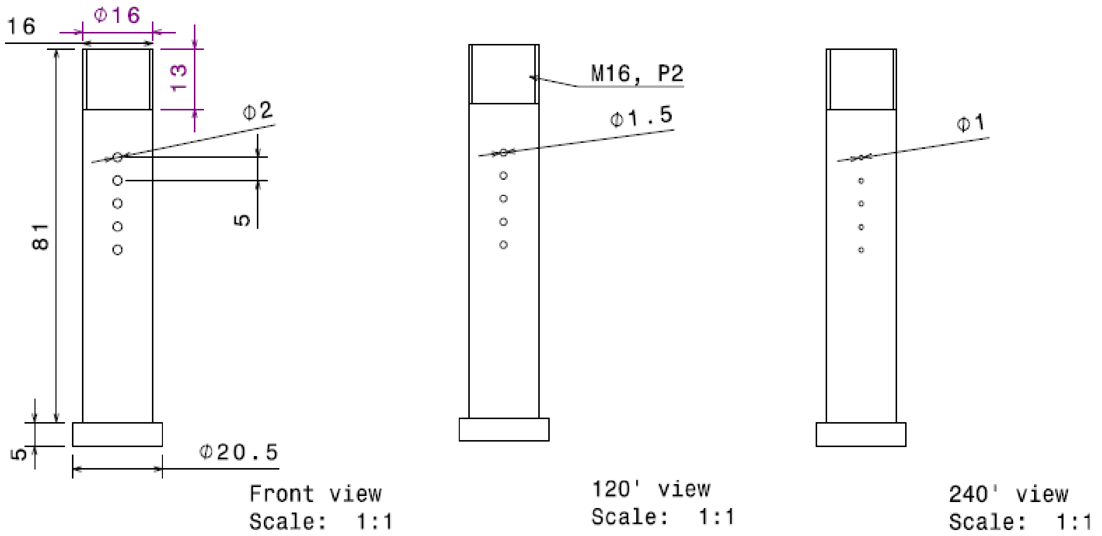


Figure 22 Modification done to the inner part of sprinkler

For the outer part, nozzles arranged in the shape of eclipse are introduced. The nozzles are 5 mm apart vertically from one center to another and 30^0 offset. This modification is shown in Figure 23.

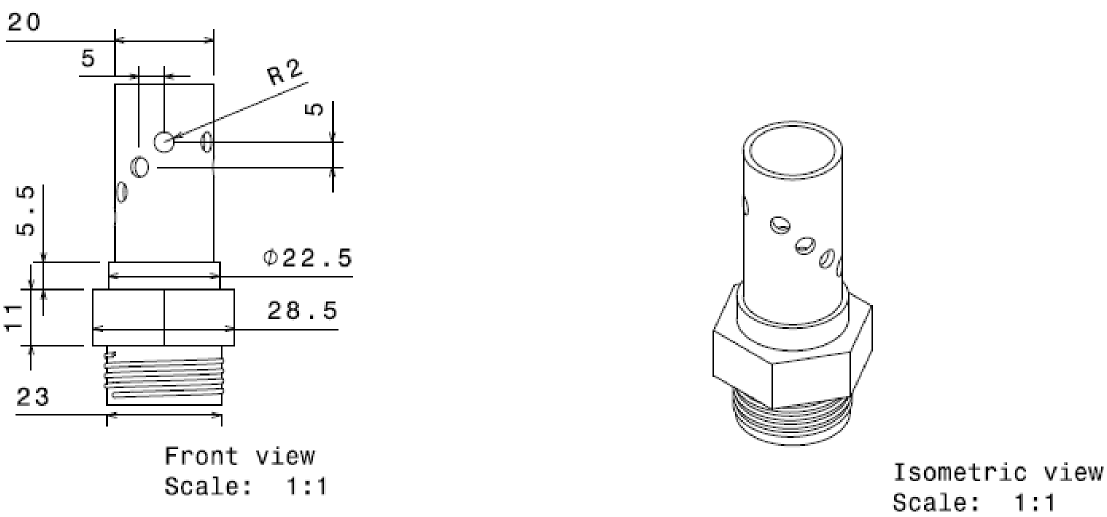


Figure 23 Modifications done to outer part of sprinkler

During operation, the inner part will rotate together with the main part. The outer part will act as valve, opening and closing the nozzle on the inside when nozzles on both parts are aligned. The design of Smart Sprinkler limits the number of nozzle opened to be 3 at an instance. This is important to maintain the pressure of the sprinkler. The concept of flow and pressure is explained in detail under Sprinkler Theory section.

One of the most crucial concern throughout this project is water leakage coming from the bottom (inner and outer) part of smart sprinkler. This water leakage will interrupt the trajectory of the sprinkler water, flow rate of the sprinkler and indirectly, the rate of rotation. Therefore, a modification to the original design is introduced. The original part is tapered and 0.5 mm clearance. To reduce leakage, the tapered part is designed to be straight and the clearance is reduced to 0.1 mm for Smart Sprinkler.

Aligned with this modification, the thread OD has to be changed from 15.7 mm to 16.0 mm, following the metric standard unit.

3.5 Detailed Drawing Assembly

Detailed drawing of the selected model is to be developed using CATIA. Detailed drawing developed is shown in Appendix III.

3.6 Fabrication

Detailed drawing is to be used for fabrication.

3.7 Testing

Upon completion of fabrication, the smart sprinkler is to be tested using a simplified version of “Catch Can” experiment to obtain water distribution. The result will then be analyzed.

The procedure of testing is as follows:

1. Preparation of all materials and apparatus is done accordingly.
    - 3 empty buckets(367 mm x 263 mm)
    - 100 ml measuring cylinder
    - 250 ml measuring cylinder
    - Measuring tape
    - Data checklist
    - 9 m string
    - Stopwatch

2. Observation of the distance covered, rate of rotation and flow rate is done and recorded at the beginning of the experiment.
3. A straight line from the sprinkler head to the furthest distance covered by the sprinkler is made using a 9 m string.
4. The water collecting is done by meter. The experiment is started with 1 m and continued subsequently i.e. 2 m, 3 m...nth m.
5. Arrangement of buckets labeled as Bucket 1, 2, and 3 is done along the first 1 m as shown in Figure 1.

6. Before starting the experiment, the starting position of the sprinkler head i.e. the direction of the water jet is determined and set. In this experiment, the main nozzle is facing 180^o away from the direction of the bucket. The whole set up is as shown in Figure 24.

Figure 24 Position of sprinkler main nozzle facing away from buckets at the beginning

7. Water supply is turned on and the collection of water is done for 10 rotations.
8. The water collected are recorded and tabulated.
9. The starting position is adjusted to the initial direction.
10. Step 5-9 is done for the subsequent meters until the furthest coverage.
11. Results are recorded and tabulated.

Pictures taken during testing is shown in Appendix II.

3.8 Project Final Report

By consolidating all details and findings, final report will be produced.

3.9 Catch Can Test

This experiment will be conducted to characterize the uniformity of water distribution of sprinkler packages installed on center pivots and lateral move irrigation system by employing the test procedures guideline of ANSI/ASAE S436.1 DEC01 (“Test Procedure”, 1989). The test procedures are as follows:

Before Testing:

1. Before a machine is tested, it shall be verified that the sprinkler package has been installed and adjusted according to the design specifications. If not installed or adjusted properly, the package shall be corrected before testing.

2. The desired test pressure shall be specified prior to the test. For many applications the specified test pressure should match the pressure used to design the sprinkler package on the machine. The test pressure shall be recorded and shall be maintained during the test to within 6 5% of the specified test pressure. The pressure-measuring device shall be capable of accurately measuring to within 6 2% of the specified test pressure.

3. The machine shall be operated at a speed that will deliver an average depth of application of not less than 15 mm. The irrigation system shall be operated long enough for the water application pattern to completely pass over all collectors.

4. The application depth data shall be recorded by measuring the volume or mass of water caught in the collectors. The measuring device shall be accurate to 63% of the average amount of water collected.

5. Obviously erroneous observations caused by leaking or tipped containers, or other explainable variances, may be eliminated from the water distribution analysis. The number of deleted observations shall not exceed 3% of the total number of depth measurements. All observations shall be reported. The number of obviously wrong observations and reasons for the deletion shall be recorded.

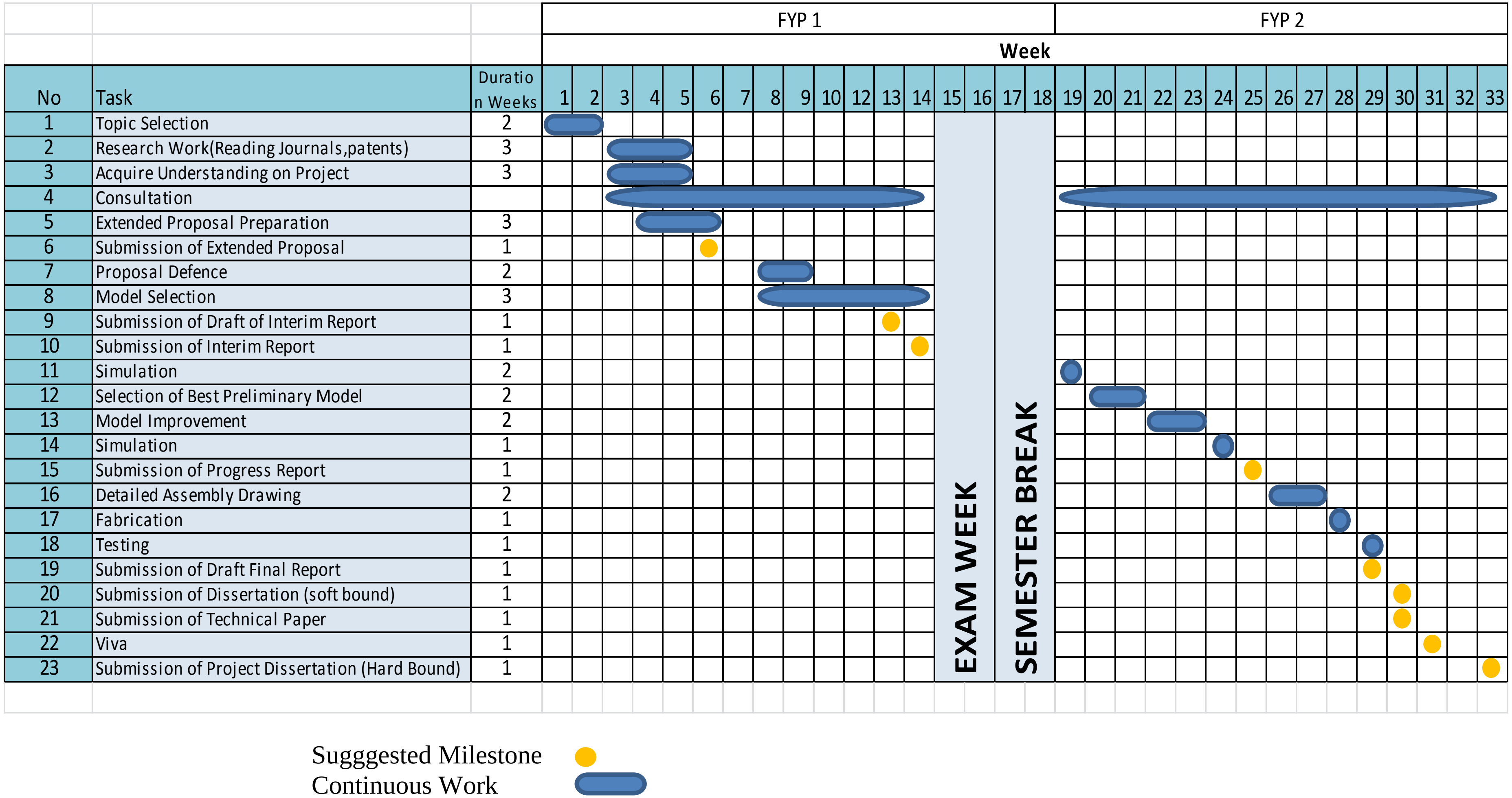
6. Observations beyond the effective radius or length of the machine shall be eliminated from the analysis.

During Testing:

1. The collectors shall be located along lines extending radially from the pivot point. If lines of collectors are too far apart, the duration of the test becomes excessive and environmental conditions or topographic features may change during the test. Therefore, distal ends of the radial lines shall be no more than 50 m apart.

2. Collectors are not required for the inner 20% of the effective radius of the pivot if mutually agreed upon by the testor and the client.

3.10 Gantt Chart



CHAPTER 4

4.1 RESULTS

This section will compare the theoretical data obtained through analysis and calculation using empirical formulae and experimental data regarding water distribution of the sprinkler.

4.1.1 Original Model

4.1.1.1 Theoretical Data

The water distribution of sprinkler over its covered area is calculated using its flow rate, Q and rate of rotation, rpm. These two parameters are measured during the water distribution experiment carried out. Apart from that, the radius of wetted are is also measured. The data is shown below.

a) Flow rate, Q (ml/s)

Measurement of flow rate is done during experiment and is recorded. 3 trials are done and the average flow rate is calculated and recorded in Table 3.

Table 3 Recorded data of flow rate

Trial	Volume, ml	Time, s
1	606	2
2	602	2
3	596	2
Average	601	2

Therefore, the average flow rate is **300.5 ml/s.**

b) Rate of rotation

3 trials are done in determining the rate of rotation of the original sprinkler. Observation is done for 5 rotations and the time elapsed are recorded in Table 4.

Table 4 Recorded data of rate of rotation

Trial	No of rotations	Time, (s)
1	5	18.62
2	5	17.99
3	5	18.16
Average	5	18.26

Therefore, the rate of rotation for original model is approximately 16 rpm.

By knowing Q and rate of rotation of the sprinkler, the amount of water applied over the designated area in 1 second can be calculated and is found to be **3.423 ml/m^2**.

4.1.1.2 Experimental Data

a) Water Distribution

Distance covered: **10 meters**

Water collection:

The data for volume of water collected is shown in Table 5.

Table 5 Volume of water for every distance covered

Bucket	Distance									
	1st (ml)	2nd (ml)	3rd (ml)	4th (ml)	5th (ml)	6th (ml)	7th (ml)	8th (ml)	9th (ml)	10th (ml)
1	13	14	11	12	9	8	10	13	15	14
2	10	9	11	8	7	8	13	12	14	16
3	14	16	15	9	8	9	8	15	20	12
Total	37	39	37	29	24	25	31	40	49	42

From the water distribution data, water distribution per area is calculated and found to be **12.191 ml/m^2**

4.1.2 Smart Sprinkler

4.1.2.1 Theoretical Data

The water distribution of sprinkler over its covered area is calculated using its flow rate, Q and rate of rotation, rpm. These two parameters are measured during the water distribution experiment carried out. Apart from that, the radius of wetted are is also measured. The data is shown in below.

a) Flow rate, Q (ml/s)

Measurement of flow rate is done during experiment and is recorded in Table 6. 3 trials are done and the average flow rate is calculated.

Table 6 Recorded data of rate of rotation

Trial	Volume, ml	Time, s
1	422	2
2	430	2
3	402	2
Average	418	2

Therefore, the average flow rate is **209 ml/s.**

b) Rate of rotation

3 trials are done in determining the rate of rotation of the original sprinkler. Observation is done for 5 rotations and the time elapsed are recorded in Table 7.

Table 7 Recorded data of rate of rotation

Trial	No of rotations	Time, (s)
1	5	20.96
2	5	21.42
3	5	21.37

Therefore, the rate of rotation for original model is approximately **14 rpm**.

By knowing Q and rate of rotation of the sprinkler, the amount of water applied over the designated area in 1 second can be calculated and found to be **5.819 ml/m^2.**

4.1.2.2 Experimental Data

The experiment is done following procedures carried out for the original model.

a) Water Distribution

Distance covered: **7 meters**

Water collection:

Data for volume of water is tabulated in Table 8.

Table 8 Volume of water for every distance covered

Bucket	Distance						
	1st (ml)	2nd (ml)	3rd (ml)	4th (ml)	5th (ml)	6th (ml)	7th (ml)
1	20	11	19	5	9	7	15
2	16	15	18	11	10	11	16
3	14	17	13	10	10	10	15
Total	50	43	50	26	29	28	46

From the water distribution data, water distribution per area is calculated and found to be **13.419 ml/m^2.**

Calculations for volume of water per unit area is shown in Appendix I.

4.2 RESULTS COMPILATION

All the results (theoretical and experimental) are tabulated in Table 9.

Table 9 Data compilation

		Original Model	Smart Sprinkler
Flow Rate (main nozzle), ml/s		300.5	209.0
Rate of Rotation, rpm		16	14
Radius of wetted area, m		10	7
Volume of water, ml	Theoretical	300.5	209
	Experimental (1 rotation)	35.3	27.2
Area covered, m^2	Theoretical	87.785	35.915
	Experimental	2.896	2.0269
Volume of water per unit area, ml/m^2	Theoretical	3.423	5.819
	Experimental	12.191	13.419

4.3 GRAPHS AND DISCUSSION

Figure 25 shows the graph of volume of water vs distance covered between original model and Smart Sprinkler.

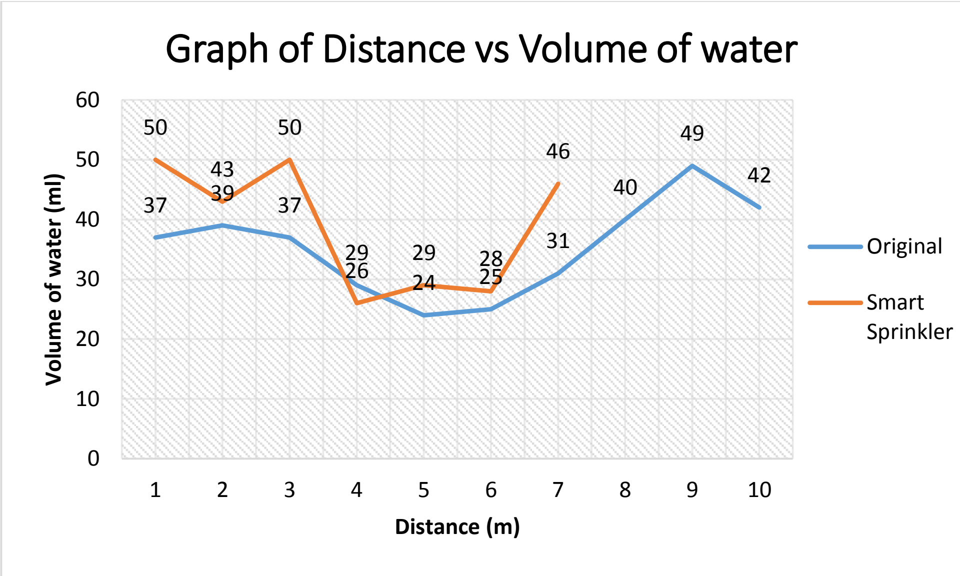


Figure 25 graph of volume of water vs distance covered between original model and Smart Sprinkler

From the graph, various informations are extracted and shown in table 10.

Table 10 Data extracted from graph

Data	Original Model	Smart Sprinkler
Mean	34.56	38.86
Median	37	43
Maximum	49	50
Minimum	24	26
Range	25	24

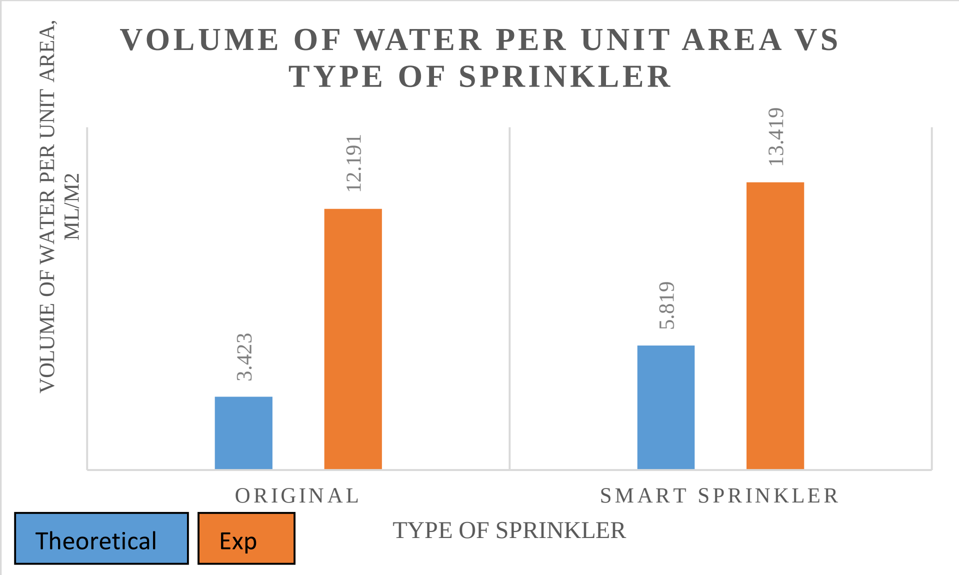


Figure 26 Graph of volume of water vs type of sprinkler

From the graph, it can be seen that the theoretical and experimental values between both original model and smart sprinkler are different. However, the relationship is the same; volume of water per unit area for Smart sprinkler is higher than that of original model. Referring to the theoretical values of both sprinklers, the value of smart sprinkler is higher. This is due to the area of coverage, calculated from radius of wetted area for Smart Sprinkler is lower than original model. It is true that the flow rate for Smart Sprinkler is lower, but the ratio between flow rate and area of coverage is higher than original model. This reasoning also applies to the experimental values of volume of water per unit area for both types of sprinkler. Apart from that, Smart sprinkler has a lower rate of rotation, allowing more water to be sprinkled at the same area of the original model.

Referring to Table X, it is noticeable that the flow rate for Smart Sprinkler is lower than the original model. This is explained in detail in Section 3.3.

In terms of radius of wetted area, the value for smart sprinkler is lower which is 7 meters compared to 10 meters of original model. This is explainable by equation 5 related to Bernoulli's equation and equation 17, 19 and 20 under water trajectory. From equation 5,

$$p = \frac{\rho}{2} v^2$$

Therefore,

$$p \; \alpha \; v$$

Pressure is directly proportional to velocity. From original model to Smart sprinkler design, the flow rate decreases. From Bernoulli's equation also,

$$Q = AV$$

Therefore,

$$Q \; \alpha \; V$$

Flow rate is directly proportional to flow rate. When flow rate decreases, the velocity decreases provided that the area of opening remain constant.

From equation 20,the radius of wetted area is given by:

$$R_j = x_1 + x_2$$

From equation 17 and 19,

$$x_1 = V_0 \cos \alpha \, t_1$$

$$x_2 = V_0 \cos \alpha \, t_2$$

where x_1 and x_2 are both directly proportional to initial velocity of water stream. Therefore, when the velocity decreases, the radius of wetted area also decreases.

In terms of accuracy of data, there are some errors particularly during the testing of the sprinklers. When taking the reading of volume of water, eye position might not be perpendicular to the water level. Apart from that, in terms of machining (drilling), the nozzles might not be 100% straight as it is done manually.

CHAPTER 5

CONCLUSION & RECOMMENDATION

At the end of the project, all objectives are managed to be achieved. The author has been able to study the principle of nozzle in improving flow and at the same time design and produce Smart Sprinkler with improved water application uniformity. From Figure 25 and 26, it can be concluded that the design of Smart Sprinkler is effective in improving water application uniformity.

To further improve this project, the author would like to suggest a few important points.

- For testing, instead of using buckets arranged in a straight line to collect water, use sector-like V-shaped bucket. This will help to improve the accuracy and comparability of the result between theoretical and experimental value.

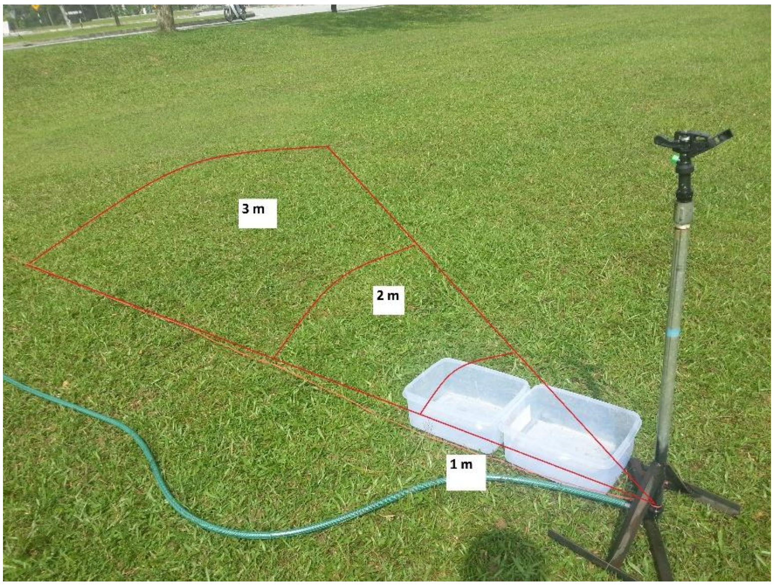


Figure 27 Recommended type of water collector

- In measuring volume of water, use a suitable accuracy to obtain a much more accurate reading.

- During fabrication of prototype, please select a suitable machine with high accuracy to produce a much more reliable prototype and result during testing.

- Perform simulation to obtain optimum design before fabrication to ensure on-time project success.

As a conclusion, this project has been a successful one with all the objectives are achieved.

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Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot and Lateral Move Irrigation Machines Equipped with Spray of Sprinkler Nozzles (1989).

APPENDIX

Appendix I

Calculation of Volume of water per unit area, ml/m²

Original model

Theoretical

$$Q = 300.5\ ml/s$$

$$V_t = Q\ x\ t$$

$$V_{1s} = 300.5\ \frac{ml}{s}\ x\ 1s$$

$$\boldsymbol{V_{1s} = 300.5\ ml}$$

$$Rate\ of\ rotation = \frac{16\ rpm}{60\ s}$$

$$Rate\ of\ rotation = 0.2667\ rps$$

$$angle\ of\ rotation\ in\ 1\ s = \frac{0.2667}{1}\ x\ 360° = 96.012° = 1.6757\ rad$$

Using formula for area of sector, covered area of sprinkler for 1 sec is calculated.

$$sA = \frac{\theta}{2}\ x\ r^2$$

$$A = \frac{1.6757\ rad}{2}\ x\ (10\ m)^2$$

$$\boldsymbol{A = 83.785\ m^2}$$

Therefore, the theoretical water distribution for original model is:

$$\boldsymbol{\frac{V_{1s}}{A} = \frac{300.5\ ml}{83.785\ m^2} = 3.423\ ml/m^2}$$

Experimental

$$Volume\ of\ \ water\ per\ unit\ area = \frac{V_{total}}{A}$$

$$V_{total} = \frac{(37 + 39 + 37 + 29 + 24 + 25 + 31 + 40 + 49 + 42)\ ml}{10\ rotations}$$

$$\boldsymbol{V_{total} = 35.3\ ml}$$

$$A = 3\ bucket\ per\ meter\ x\ (327\ x\ 263)\ x\ 10\ m$$

$$\boldsymbol{A = 2.8956\ m^2}$$

$$\boldsymbol{\frac{V_{total}}{A} = \frac{35.3\ ml}{2.8956\ m^2} = 12.191\ ml/m^2}$$

Smart Sprinkler

Theoretical

$$Q = 209\ ml/s$$

$$V_t = Q\ x\ t$$

$$V_{1s} = 209\ \frac{ml}{s} x\ 1s$$

$$\boldsymbol{V_{1s} = 209\ ml}$$

$$Rate\ of\ rotation = \frac{14\ rpm}{60\ s}$$

$$Rate\ of\ rotation = 0.2333\ rps$$

$$angle\ of\ rotation\ in\ 1\ s = \frac{0.2333}{1} x\ 360° = 83.988° = 1.4659\ rad$$

Using formula for area of sector, covered area of sprinkler for 1 sec is calculated.

$$sA = \frac{\theta}{2}\ x\ r^2$$

$$A = \frac{1.4659\ rad}{2}\ x\ (10\ m)^2$$

$$\boldsymbol{A = 35.9146\ m^2}$$

Therefore, the theoretical water distribution for original model is:

$$\boldsymbol{\frac{V_{1s}}{A} = \frac{209\ ml}{35.9146\ m^2} = 5.8194\ ml/m^2}$$

Experimental

$$Water\ distribution\ per\ area = \frac{V_{total}}{A}$$

$$V_{total} = \frac{(50 + 43 + 50 + 26 + 29 + 28 + 46)\ ml}{10\ rotations} = \boldsymbol{ml}$$

$$\boldsymbol{V_{total} = 27.2\ ml}$$

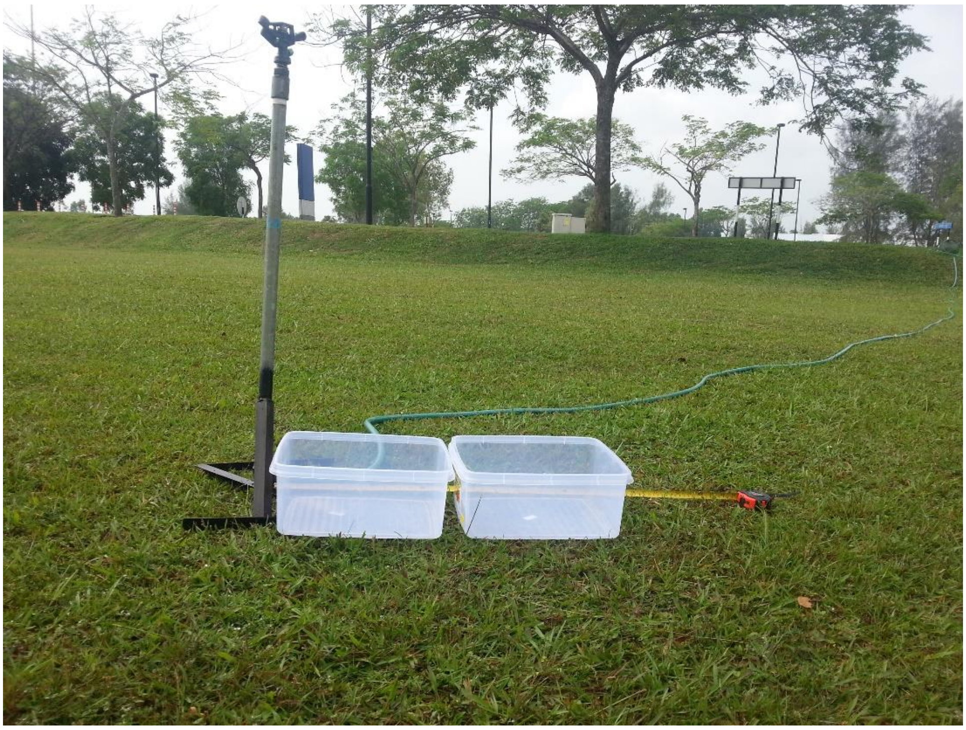
$$A = 3\ bucket\ per\ meter\ x\ (327\ x\ 263)\ x\ 7\ m$$

$$\boldsymbol{A = 2.0269\ m^2}$$

$$\boldsymbol{\frac{V_{total}}{A} = \frac{27.2\ ml}{2.0269\ m^2} = 12.419\ ml/m^2}$$

Appendix II

Pictures taken during Testing



Appendix III

Detail Drawings