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Improving a Manual Operated Household Irrigation System for Efficient Operation using an Irrigation System Controller

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Abstract

In most residential irrigation systems one of the major problems that are being faced is low pressures in irrigation pipeline systems that usually results in sprinklers not functioning properly. These low pressures are usually due to poor pipeline system designs. This study is aimed at designing and testing the best pipeline network for a household irrigation system that will be able to deliver high pressures. An irrigation system controller is also added to the irrigation system to further improve the irrigation system efficiency which will in turn save water and allow irrigation system owners to be able to operate their irrigation system from anywhere if they have internet connection. The parameters that were used to model the pipe network were velocity, pressure, pipe diameter and volume flow rate. It was discovered that these factors contributed significantly to the pipe network performance. A recommended fluid velocity that did not allow the occurrence of water hammer was used to determine the pipe diameters depending on the line total volume flow rate requirements. Among the two pipeline network designs that were tested using the same fluid and pressure requirements, it was discovered that one pipeline system used very small pipe diameters throughout the whole pipe network and was able to produce good results with an even distribution of pressure and emitter exit flow rates. The other pipeline network system that was arranged in a tree pattern used very big pipes and had an uneven distribution of pressure and flow rates across the whole system with emitters that are connected further away from the main supply line failing to meet emitter exit requirements.

Keywords: pressure, flow rate, velocity, pipe diameter and efficiency

1.1 INTRODUCTION

For gardens to remain in good condition they rely on constant water supply from time to time. This water supply is usually supplied through a series of pipes hidden underground or through a tap and hosepipe configuration. These irrigation systems that are being used currently use valves that are turned on and off manually by turning the valve knobs. Therefore, they require human physical interactions with the system for it to function. This can be quite stressful to home or nursery owners if they want to leave their property for a holiday and do not have anyone who is going to operate the irrigation system while they are away. When plant lovers feel like taking a break by going for a holiday for a few weeks or months they face challenges such as who is going to water their gardens while they are away.

The main objection of this study is to design an irrigation pipeline network that will use a reservoir and irrigation system controller that will eliminate the manual watering systems in homes or nurseries. Using the principles of fluid mechanics and the latest technology that is now available in irrigation systems field, a remote-controlled household irrigation system that can be operated using the internet was studied. This was achieved by designing a water pipeline system that consists of control valves instead of traditional manual valves, an independent reservoir that stores water for the garden, a pump and a control system that is controls the operation of valves and a pump.

1.2 METHODOLOGY

A pipeline network is a system of pipes and trenches forming several circuits or loops providing the required quantity and quality of water to a specific location.

Tree or branched Pipeline network

The pipeline distribution system that was used for this project is a tree or branched system. In a branched system only one main supply pipeline supplies water to sub-mains. These sub-mains further divide into several other branched lines and each branch outlet receive its supply from only one route. (Karmeli et al., 1968; Gupta, 1969; Hamberg, 1974) developed this system and it forms the backbone to which other pipeline systems were derived such as closed loop systems. To obtain the best results when using this system in irrigation applications, the land is divided into zones to avoid the need of using very big pumps to operate the whole system at once and to allow a uniform pressure distribution across emitters.

The tree or branched pipe system design will solve the current problem of low pressures and lack of sprinklers coverage irrigating the whole surface area of the household garden. The tree system allows the garden to be divided into zones and this makes it possible for the irrigation system to be operated with a smaller booster pump since the garden can be irrigated in sections one at a time.

Advantages of branched system

- The overall design calculations are easy and simple
- Land can be divided into zones and can be watered independently

- It uses very few cut off valves and has a very low operation and maintenance cost
- Simple pipe laying

Disadvantages of branched system

- The system is not good at maintaining satisfactory pressures to areas located further away for the main line.
- Only one main line supplies the water
- Head losses are very high therefore large pipe diameters are and large pumping units are required. The presents of dead ends affect the water quality since they allow sedimentation. Water hammer has an ability to make pipes burst.

Equations of Fluid behavior inside a pipe

Reynolds number N_R

$N_R = \frac{\upsilon D\rho}{\eta}$

If $N_R < 2000$, the flow is laminar

If $N_R > 4000$, the flow is turbulent

$f = \frac{64}{N_R}$ Friction factor for laminar flow

$f = \frac{0.25}{\log\left[\frac{\varepsilon}{3.70}+\frac{5.74}{N_R}\right]^2}$ Friction factor for turbulent flow

$h_L = K\,\frac{v^2}{2g}$ (fittings and valves)

$h_L = f\,\frac{L}{D}\,\frac{v^2}{2g}$ (Frictional losses)

Where;

f – Friction factor

L – Length of pipe

D – Diameter of the pipe

v – Average velocity

h_R – energy removed from fluid e.g., a mechanical motor.

Therefore, the general energy equation of the system.

$$\frac{P_1}{\gamma} + \frac{{v_1}^2}{2g} + z_1 + h_A + h_L + h_R = \frac{P_2}{\gamma} + \frac{{v_2}^2}{2g} + z_2$$

Dynamic viscosity (η) which is the measure of a fluid internal resistance to flow. The dynamic viscosity of water at 25°C is 8.90×10^{-4} Pa·s.

Number of sprinklers required and sprinkler head spacing pattern

According to tests conducted by the Center for Irrigation Technology (CIT) to test the most efficient combination of sprinkler nozzles to apply water. It was found that the area under 60% of the sprinkler's distribution radius is the area that received sufficient water for plant growth without the need for sprinkler overlapping. Beyond this 60% line the volumes of water diminish as you move further away from it and becomes less effective to support plants.

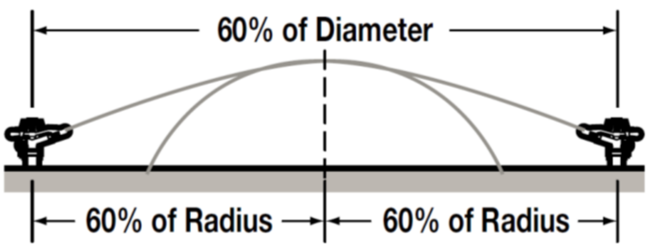

Figure. 1: 60% diameter sprinkler spacing

To determine the number of sprinklers required by the residential area, measure and draw the property or obtain a google maps image of the property and then use any CAD software to draw the property to scale. All the property details such as walls, walkways, fences, and driveways need to be indicated on the drawing. From the drawing the property will need to be divided up into zones such as back yard, front yard, side yard, lawns, flowers, etc. Sprinklers are selected according to their applications and using the same type of sprinklers for each zone. Figure 3.1.4–4 below shows how sprinklers should represent on the property drawing.

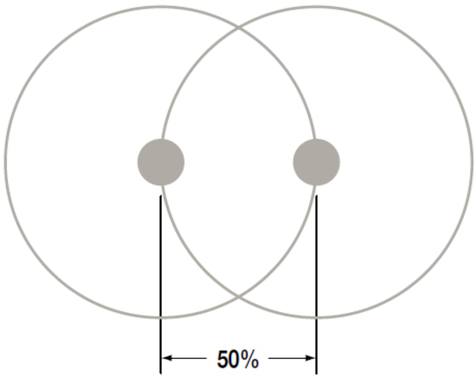

Figure. 2 Sprinkler spray representation on property drawing

Pipeline network Layouts

Two pipeline network designs shown below were designed and simulated to see how they operated in the different zones across the different zones of the garden.

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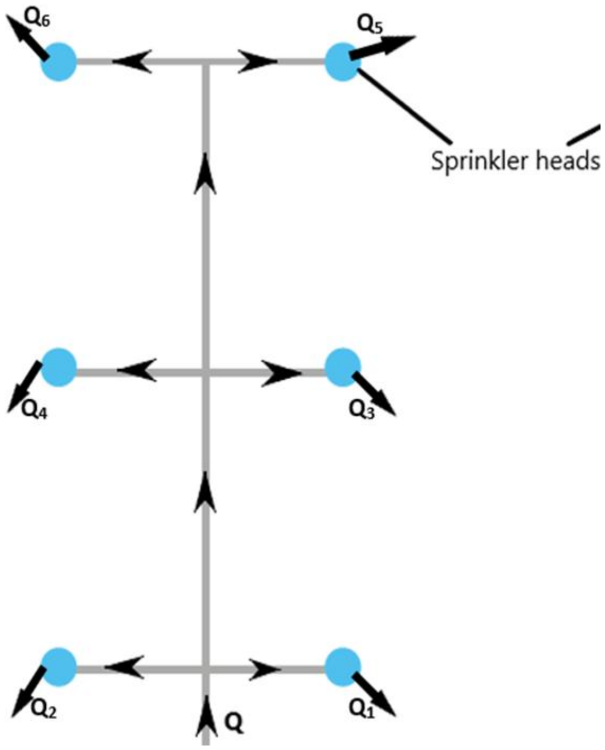
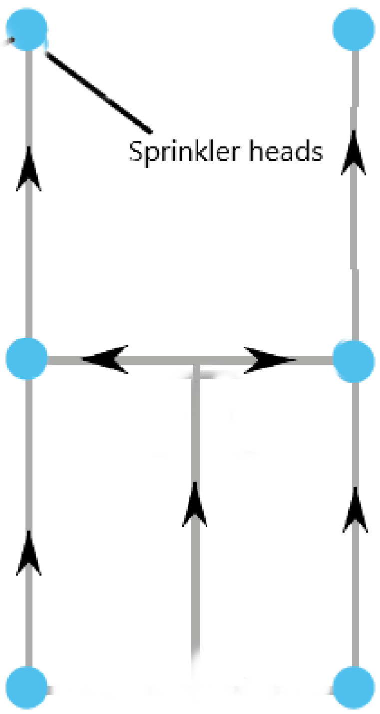


Pipeline network for Idea 1

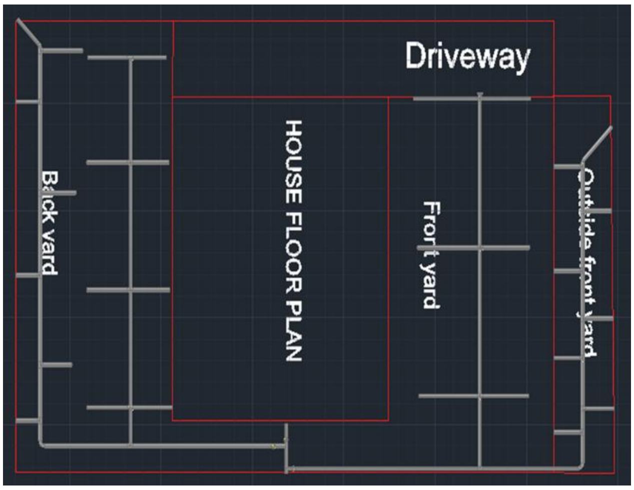


Pipeline layout for Idea 2

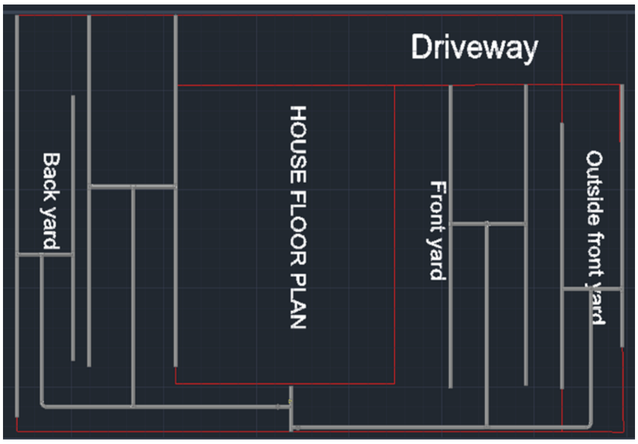
The above pipeline networks arrangements were simulated using PipeFlo Professional to see which pipeline network layout was best to be employed in a specific zone. The simulation was done using the same parameters such as zone pressure and fluid flow rate requirements that were required for the zone to function properly.

1.3 Results and Discussion

Two possible types of pipeline layouts were designed and simulated. The first design was a pipe network that was a tree layout (idea 1) with a main that consists of branches that moves from the main towards the sprinklers and the other design was a pipe network in the form of an H (idea 2). These pipe line networks were simulated using **PipeFlo Professional** and the demands for a specific zone were applied to the two different designs in order to get more accurate results and to further guarantee the accuracy of results and discussion.



Idea 1 pipeline layout for the different zones



Idea 2 pipeline layout for the deferent zones

The following are the results that are simulated using PipeFlo Professional

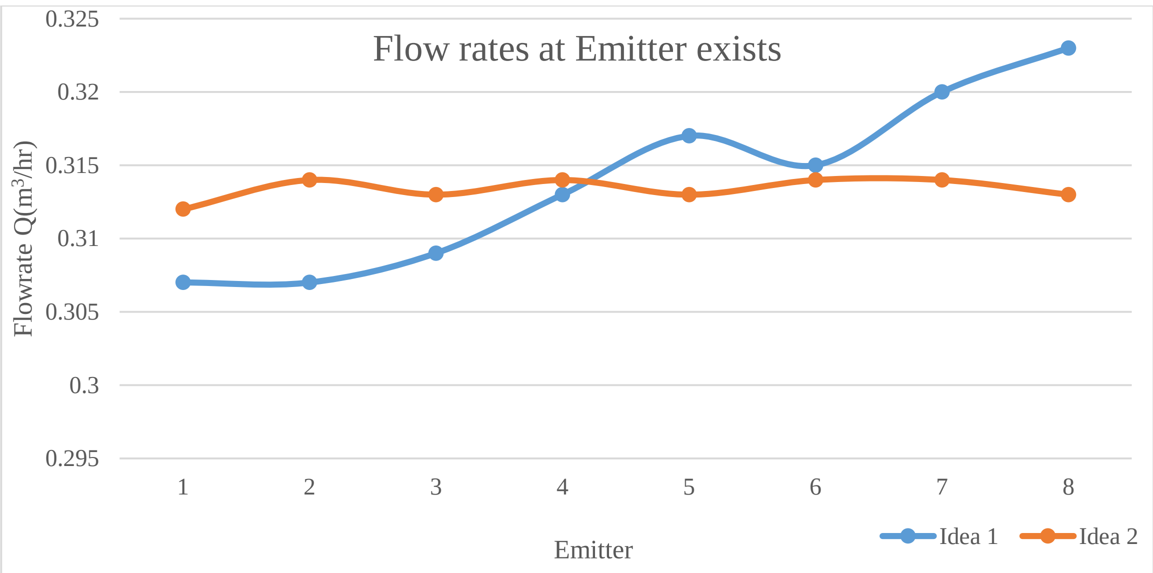
Emitter or sprinkler exit results

Table 1. Zone A sprinkler results for Idea 1

Zone A					
Emitter	Q required (m^3/hr)	Q simulated (m^3/hr)	Velocity (m/s)	Pressure required (Bar)	Simulated pressure (Bar)
1	0.30	0.307	0.434	2	2.094
2	0.30	0.307	0.435	2	2.094
3	0.30	0.309	0.438	2	2.12
4	0.30	0.313	0.443	2	2.176
5	0.30	0.317	0.449	2	2.231
6	0.30	0.315	0.446	2	2.201
7	0.30	0.320	0.454	2	2.285
8	0.30	0.323	0.457	2	2.315

Table 2. Zone A sprinkler results for idea 2

Zone A					
Emitter	Q required (m^3/hr)	Q simulated (m^3/hr)	Velocity (m/s)	Pressure required (Bar)	Simulated pressure (Bar)
1	0.30	0.312	0.442	2	2.172
2	0.30	0.314	0.444	2	2.185
3	0.30	0.313	0.444	2	2.185
4	0.30	0.314	0.445	2	2.199
5	0.30	0.313	0.444	2	2.185
6	0.30	0.314	0.445	2	2.199
7	0.30	0.314	0.444	2	2.188
8	0.30	0.313	0.444	2	2.182



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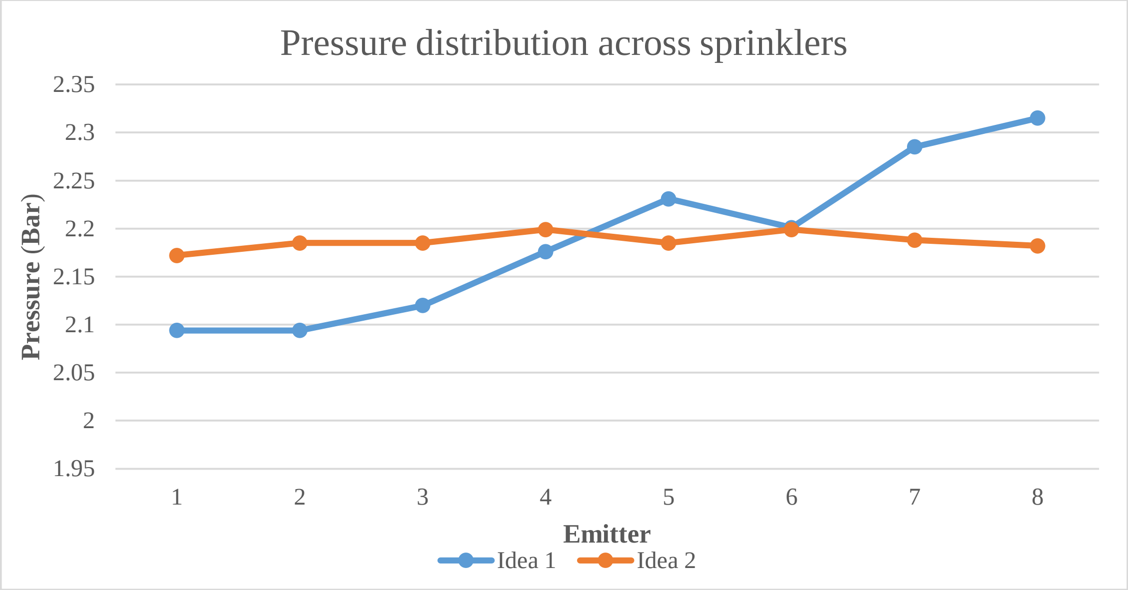


Zone A pressure and Flow rate distribution curve

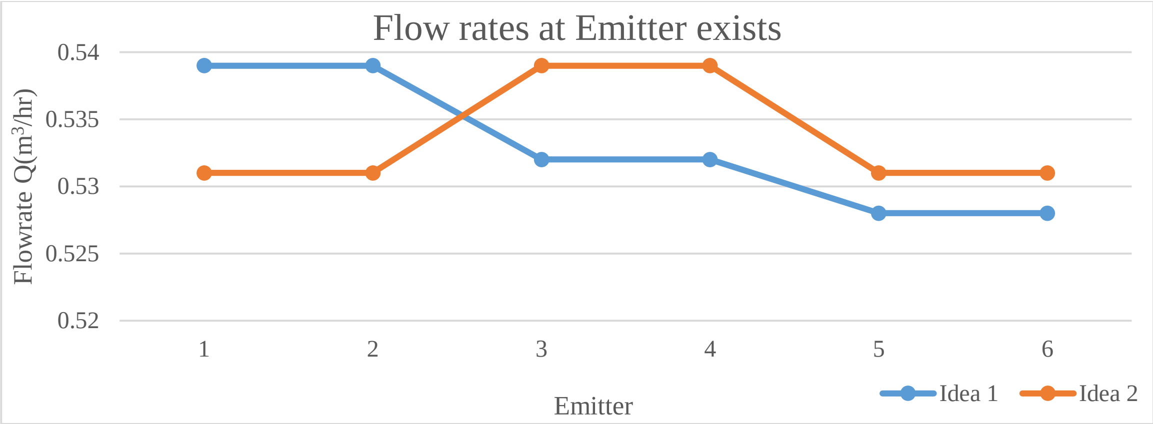
The above graphs show the different results that were obtained from the simulation of the two types of pipeline layouts. As can be seen from the table of results and graphs both layouts were able to meet the sprinklers requirements, however idea 2 produced the best results because it was able to produce a more uniform pressure and flow rate distribution across its pipeline network and thus produces less strain to sprinklers. Idea 1 produces an uneven distribution of pressure and flow rates. The pipeline network of idea 1 produces more stain to sprinklers that are closer to the supply line and they have higher pressures and volume flow rates than the one further upstream.

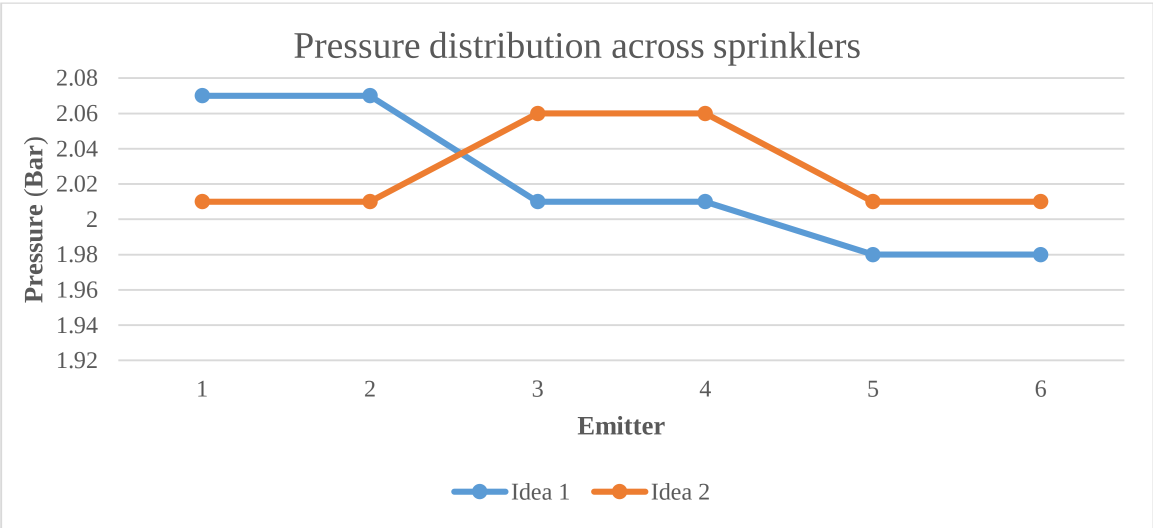
Table 3. Zone B sprinkler results for idea 1

Zone B					
Emitter	Q required (m^3/hr)	Q simulated (m^3/hr)	Velocity (m/s)	Pressure required (Bar)	Simulated pressure (Bar)
1	0.53	0.539	0.764	2	2.07
2	0.53	0.539	0.764	2	2.07
3	0.53	0.532	0.754	2	2.01
4	0.53	0.532	0.754	2	2.01
5	0.53	0.528	0.749	2	1.98
6	0.53	0.528	0.749	2	1.98

Table 4. Zone B sprinkler results for idea 2

Zone B					
Emitter	Q required (m^3/hr)	Q simulated (m^3/hr)	Velocity (m/s)	Pressure required (Bar)	Simulated pressure (Bar)
1	0.53	0.531	0.752	2	2.01
2	0.53	0.531	0.752	2	2.01
3	0.53	0.539	0.634	2	2.06
4	0.53	0.539	0.634	2	2.06
5	0.53	0.531	0.752	2	2.01
6	0.53	0.531	0.752	2	2.01





Zone B pressure and Flow rate distribution curve

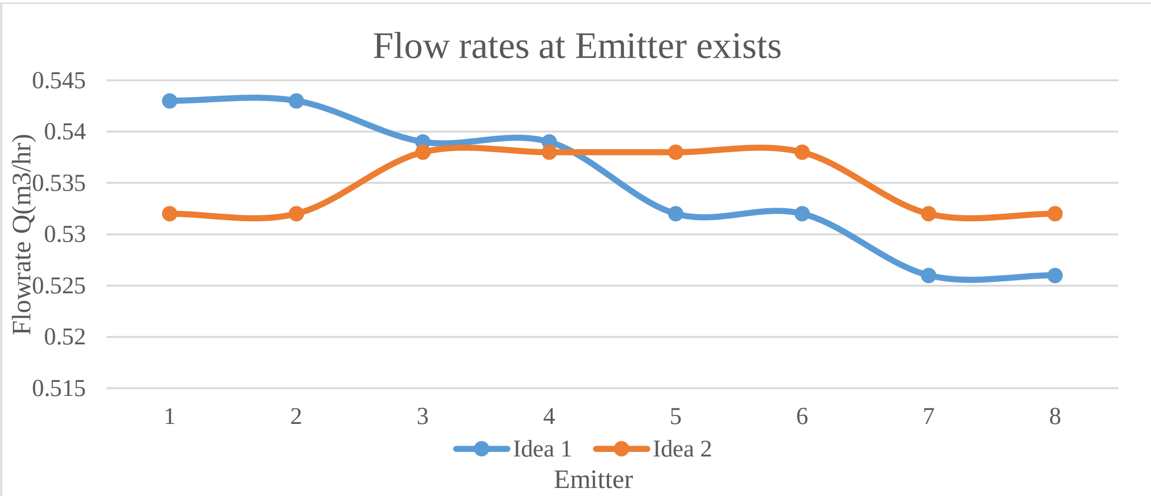
The above graphs show the different results that were obtained from the simulation of the two types of pipeline layouts. As can be seen from the table of results and graphs only idea 2 was able to meet the sprinklers requirements. Idea 2 produced the best results because it was able to meet the design requirements and produced a more uniform pressure and flow rate distribution across its pipeline network and thus produces less strain to sprinklers. Idea 1 produces an uneven distribution of pressure and flow rates. The pipeline network of idea 1 produces more stain to sprinklers that are closer to the supply line and they have higher pressures and volume flow rates than the one further upstream.

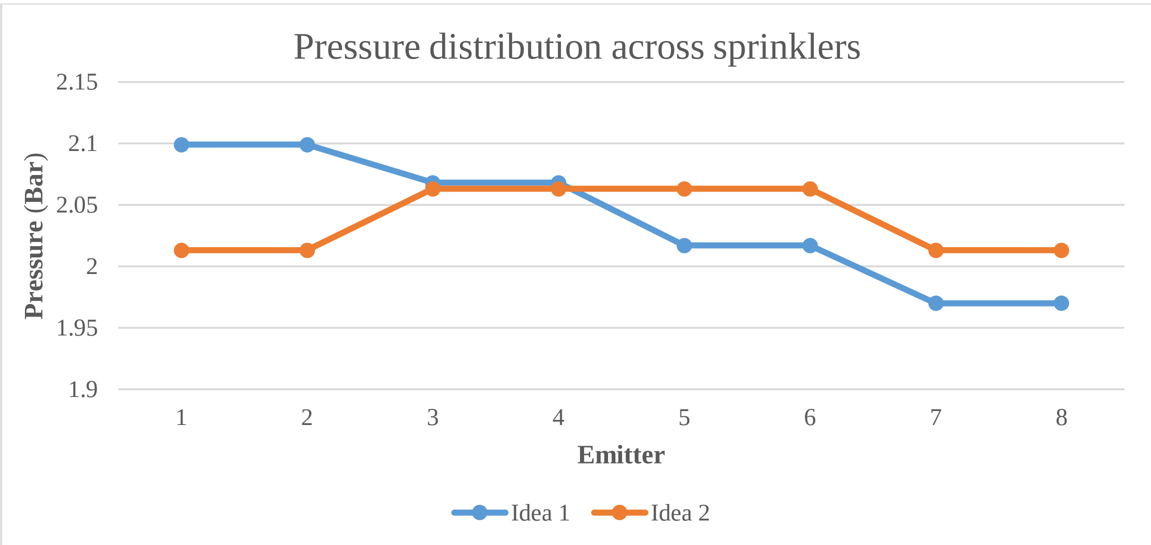
Table 5. Zone C sprinkler results for idea 1

Zone C					
Emitter	Q required (m^3/hr)	Q simulated (m^3/hr)	Velocity (m/s)	Pressure required (Bar)	Simulated pressure (Bar)
1	0.53	0.543	0.769	2	2.099
2	0.53	0.543	0.769	2	2.099
3	0.53	0.539	0.764	2	2.068
4	0.53	0.539	0.764	2	2.068
5	0.53	0.532	0.754	2	2.017
6	0.53	0.532	0.754	2	2.017
7	0.53	0.526	0.745	2	1.97
8	0.53	0.526	0.745	2	1.97

Table 6. Zone C sprinkler results for idea 2

Zone C					
Emitter	Q required (m^3/hr)	Q simulated (m^3/hr)	Velocity (m/s)	Pressure required (Bar)	Simulated pressure (Bar)
1	0.53	0.532	0.753	2	2.013
2	0.53	0.532	0.753	2	2.013
3	0.53	0.538	0.763	2	2.063
4	0.53	0.538	0.763	2	2.063
5	0.53	0.538	0.763	2	2.063
6	0.53	0.538	0.763	2	2.063
7	0.53	0.532	0.753	2	2.013
8	0.53	0.532	0.753	2	2.013





Zone C pressure and Flow rate distribution curve

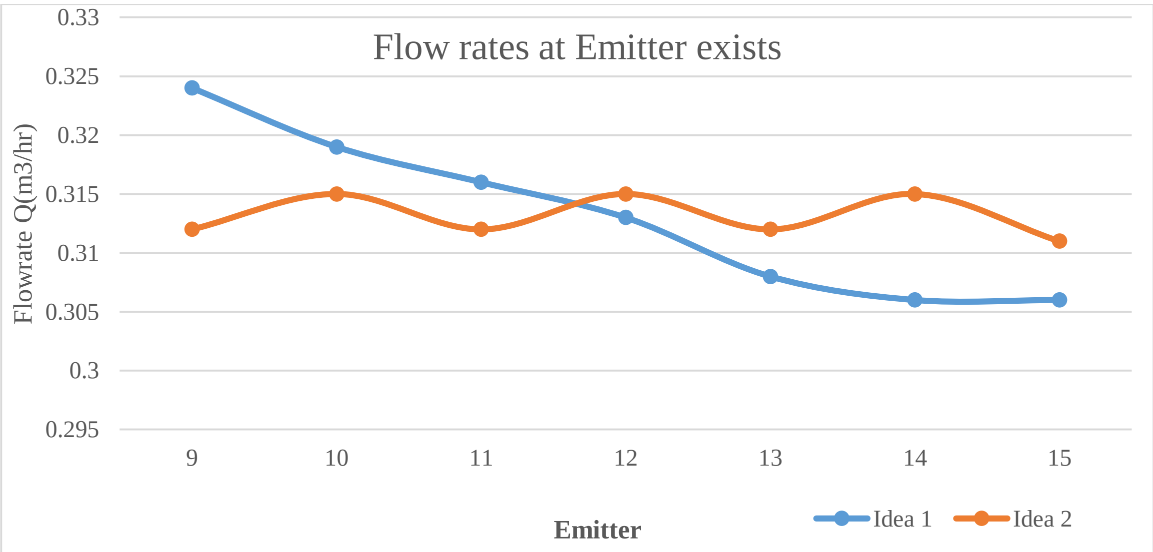
The above graphs show the different results that were obtained from the simulation of the two types of pipeline layouts. As can be seen from the table of results and graphs only idea 2 was able to meet the sprinklers requirements. Idea 2 produced the best results because it was able to meet the design requirements and produced a more uniform pressure and flow rate distribution across its pipeline network and thus produces less strain to sprinklers. Idea 1 produces an uneven distribution of pressure and flow rates. The pipeline network of idea 1 produces more stain to sprinklers that are closer to the supply line and they have higher pressures and volume flow rates than the one further upstream.

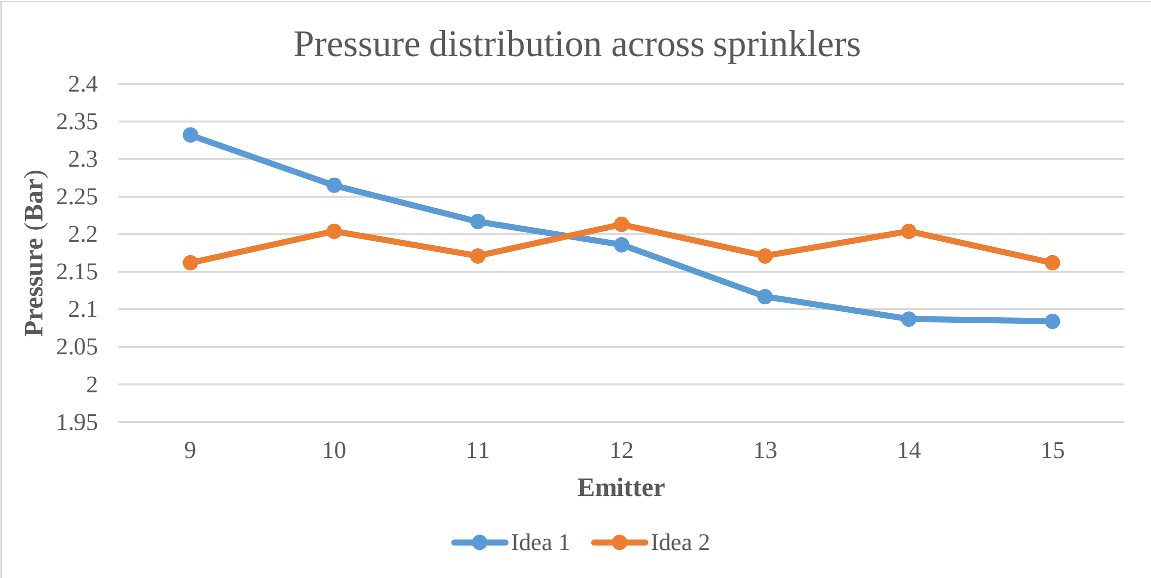
Table 7. Zone D sprinkler results for idea 1

Zone D					
Emitter	Q required (m^3/hr)	Q simulated (m^3/hr)	Velocity (m/s)	Pressure required (Bar)	Simulated pressure (Bar)
9	0.30	0.324	0.459	2	2.332
10	0.30	0.319	0.452	2	2.265
11	0.30	0.316	0.447	2	2.217
12	0.30	0.313	0.444	2	2.186
13	0.30	0.308	0.437	2	2.117
14	0.30	0.306	0.434	2	2.087
15	0.30	0.306	0.433	2	2.084

Table 8. Zone D sprinkler results for idea 2

Zone D					
Emitter	Q required (m^3/hr)	Q simulated (m^3/hr)	Velocity (m/s)	Pressure required (Bar)	Simulated pressure (Bar)
9	0.30	0.312	0.442	2	2.162
10	0.30	0.315	0.446	2	2.204
11	0.30	0.312	0.443	2	2.171
12	0.30	0.315	0.447	2	2.213
13	0.30	0.312	0.443	2	2.171
14	0.30	0.315	0.446	2	2.204
15	0.30	0.312	0.441	2	2.162





Zone D pressure and Flow rate distribution curves

The above graphs show the different results that were obtained from the simulation of the two types of pipeline layouts. As can be seen from the table of results and graphs both layouts were able to meet the sprinklers requirements, however idea 2 produced the best results because it was able to produce a more uniform pressure and flow rate distribution across its pipeline network and thus produces less strain to sprinklers. Idea 1 produces an uneven distribution of pressure and flow rates. The pipeline network of idea 1 produces more stain to sprinklers that are closer to the supply line and they have higher pressures and volume flow rates than the one further upstream.

The below discussion is based on the flow simulation which was done on Pipe Flo.

The main goal of the project was to design a pipeline network that can deliver the required standard pressure and volume flow rates that are required by each sprinkler nozzle. Two designs of possible pipeline layouts for each zone were simulated using the same amount of volume flow rates and pressure required by each zone.

Comparing the pressure and volume flow rate results attained from Idea 1 and Idea 2, we can see that in Idea 1 which is represented by the blue lines on the above graphs, as you move further from the first branch from the main line as you go towards the last sprinklers at the end of the line the pressure and volume flow rates drops sharply. This therefore leads to the sprinklers towards the end of the system not receiving enough pressure and volume flow rates for them to function properly. This problem still exists even though you use the smallest available standard pipe that can deliver the required volume flow rates in a specific pipeline at the optimum speeds and pressure are used. Head losses are more in branched lines and are indicated by the red colour which is acceptable since 2bars of pressure is required to operate a sprinkler and since water is also being lost from the system. The total volume flow rate that is required by the system is the sum of all the volume flow rates required by each sprinkler or spray nozzle. To improve the pressure and volume flow rates towards the end of the pipeline network, you simply increase the total volume flow rate that is required by the system at the pump to a value slightly above the one that is required by the system when sizing the pump in PIPE Flo, but doing so will not improve the uneven distribution of flow rates and pressure.

Idea 2 provides the best results for the pipeline network to be used on the house. If you look at the graphs for Idea 2 which are represented by the orange line curve, we can see that there is an even distribution of pressure and volume flow rates across the system for sprinklers that are position opposite to each other. The pipeline networks for idea 2 do not produce an uneven pressure and volume flow rates compared to idea 1, the results from idea 2 alternates between common values with very small difference or changes in values. Idea 2 was able to meet all the sprinkler demands under the same conditions as idea 1, while on the other hand Idea 1 failed to meet all the sprinkler demands under the same conditions.

1.4 CONCLUSION AND RECOMMENDATIONS

The main objective of the simulation was obtained. The simulation was able to pinpoint the best pipeline network for the irrigation system. The pipeline network that was able to deliver the best results under the same conditions was established. The required pressures and the volume flow rate that were needed by the sprinklers was able to be met by Idea 2 which delivered these conditions with minimum differences in pressure and volume flow rates. Idea 2 pipeline network has a more uniform distribution of pressures and flow rates across the whole pipe network.

During installation of the pipeline system, it is very important to ensure that the pipes are free of any foreign particles because they will block the sprinkler nozzles and solenoid valve. Therefore, it is important to have a compressor onsite to flash out the whole system or use water before sprinklers are connected in order free the system off dirt. It is also important to install a filter just after the pump.

ACKNOWLEDGEMENTS

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REFERENCE

[1] Dorota Z. Haman and Fedro S. Zazueta, 2017. *University of Florida IFAS extension.* [Online] Available at: https://edis.ifas.ufl.edu/wi005#IMAGE%20WI:WI005E2A [Accessed 22 April 2020].

[2] Easygardenirrigation, 2020. *Easygardenirrigation.* [Online] Available at: https://www.easygardenirrigation.co.uk/pages/garden-irrigation-planning-guide-starter [Accessed 1 April 2020].

[3] Fanie Vorster, ARC Institute for Agricultural Engineering, 2016. *Agricultural Research Council.* [Online] Available at: http://www.arc.agric.za/arc-iae/News%20Articles%20Library/Irrigation%20system%20design.pdf [Accessed 1 April 2020].

[4] Group, L. G., 2020. *Life Green Group.* [Online] Available at: http://www.lifegreengroup.co.za/life-landscapes/irrigation-sprinkler-systems/ [Accessed 3 April 2020].

[5] Institute, S. A. L., 2017. *SALI.* [Online] Available at: https://www.sali.co.za/index.php/about-sali/blog/the-six-types-of-irrigation-systems [Accessed 2 April 2020].

[6] Nuclear-Power, 2020. *Nuclear-Power..* [Online] Available at: https://www.nuclear-power.net/nuclear-engineering/fluid-dynamics/reynolds-number/ [Accessed 8 April 2020].

[7] Ostadfar, A., 2016. *Fluid Mechanics and Biofluids Principles.* 1st ed. s.l.:Simon Fraser University.

[8] PlumbingSupply, 2020. *Plumbing Supply.* [Online] Available at: https://www.plumbingsupply.com/fittings-guide.html [Accessed 17 April 2020].