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Research Article

A Light-Weight Low-Speed Stirrer for Proper Mixing of Fertilizer and Water in a Small-Scale Automated Irrigation System

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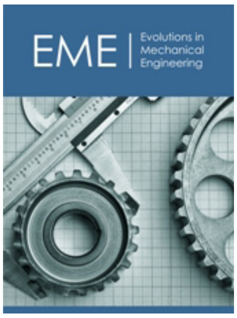

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Abstract

Proper mixing of fertilizer and water is a serious problem in a small-scale automated irrigated land observed during a visit to a farm in Kumpung Lumapas, Brunei. It is usually done manually and takes a lot of effort and time. An automatic low-speed and a lightweight stirring mechanism was designed, fabricated and installed to solve this problem using power from the same electric motor which are used to run the pump. The high speed of the rotating shaft from the existing pump was utilized and connected to a belt-pulley system to reduce its speed. The motor and pump unit were separated from direct coupling system and arranged in parallel with each other. Then, the shaft of the big pulley was linked to a speed reduction gearbox to further reduce the speed of the Polyvinyl Chloride (PVC) connected to stirrer. The performance of the belt-pulley mechanism was tested and measured with a tachometer and the outcome was a speed reduction from 2900 to 13 revolution per minute. The efficiency of the motor was also tested with and without the load to the stirring mechanism, and it was found that 8% of the motor power needs only to run the stirring mechanism. The volume flowrate of the pump was also measured before and after the stirrer installation. It was found that it had no major effect on the flowrate with the difference of 2.4 litter per minute only. The proper mixing of fertilizer and water was not the only solution to clogging problem in fertigation piping system. Other clogging factors also contributed to the difficulty such as quality of the water and incompatibility of the fertilizer.

Introduction

The research indicated that only the fertilization scheduling might significantly affect plants yields, while irrigation scheduling has a minor role. It was observed during a local farm visit that mixing of fertilizer and water (fertigation process) is a major problem in automated application of fertilization in Brunei. Mixing is done manually by labor which takes a lot of effort and time. It is further stated that sediment occurs when the mixer pump is not operated and causes the mixture to solidify and eventually clog the fertigation piping and dripper thus spoiling the crops. Proper mixing of fertilizer and water that will be injected to improve a soil is called a fertigation process. It's a norm in horticulture and cultivation as the need of accurate amount of fertilizer to control the lack of plants nutrients. Some of the common source of nourishments in fertigation are ammonium nitrate, urea, ammonia, monoammonium phosphate, diammonium phosphate and potassium chloride. Liquid and water-soluble enricher are essentials for fertigation. There are two main types of fertigation methods: The proportional approach is used in soil-less mediums where a correct amount of fertilizer stock solution is inserted into each unit of water flowing through the irrigation system. The quantitative approach is used in open fields where the farmers must choose how much nourishment should be applied per unit area [1].

This process is related to fertigation due to their repetitive occurrence in standard water-fertilizer application operation which allows consistent distribution throughout the soil. At the same time, it decreases the dependency on labor to fertilize the soil, and the controllable application of nourishment will eventually lower the cost of the operation [2]. Mixture of fertilizer and water must be soluble before it is inserted into the irrigation system, while mixing a granular type of fertilizer with water is necessary to form a basic solution. Different fertilizers have dissimilar water solubility due to their physical properties as well as the temperature and P_H of the water. Granular or crystalline type of fertilizer are mixed manually or with the help of agitator until it dissolved and reach a certain dilution. The solution is then injected to the fertigation system by using injector machines or pumps. Injecting potassium-based enricher will cause choking in the fertigation dripper since it is not soluble in water and doesn't work with other fertilizer. Potassium chloride is usually applied to plants while potassium sulfate is suitable for a sensitive crop [3]. The objectives of this project were basically to design and fabricate a prototype mechanism complete with a stirrer that would agitate the fertilizer mixture in a tank.

Methodology

An attempt was made to use the power source from the same motor used for irrigation by using two- steps speed reduction [4]. The first step was done by using a belt-pulley system so that the speed of the motor was reduced to 424RPM (Figures 1 & 2). The second step was done by using a speed reduction gearbox from the actuator and eventually reduced the stirrer speed within 10-50RPM. The power utilized by the stirrer was also determined.

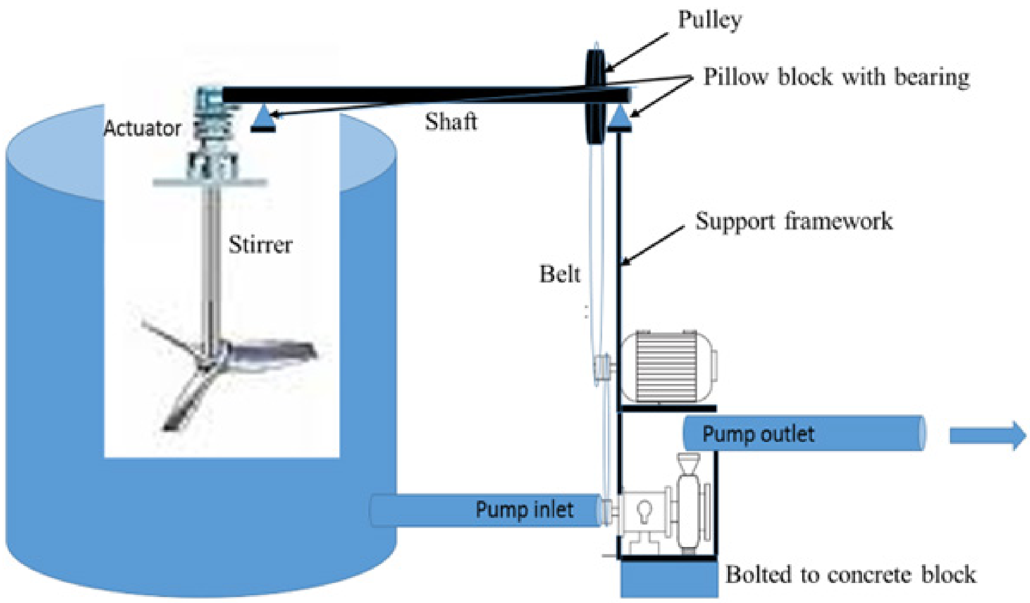

Figure 1: The stirrer powered by pump motor linked with pulley, belt and reduction gearbox.

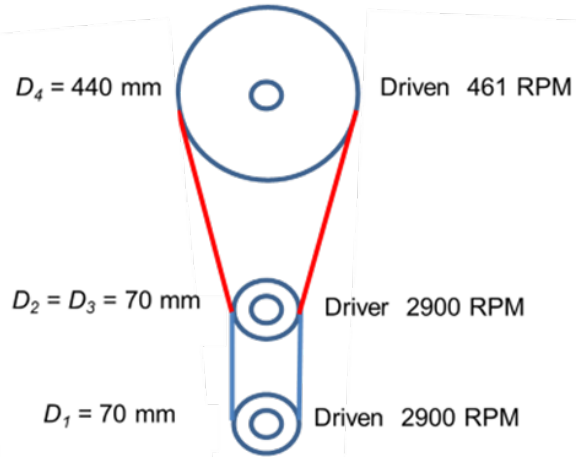

Figure 2: Pulley-belt arrangement (Speed reduction gearbox 1:36).

The proposal was selected mainly due to the readily available material. Since most of them are used items therefore the acquisition cost is affordable. All the items total cost are below five hundred Brunei dollars excluding the mixing tank and the pump unit, motor, actuator, pulley, belts which are contributed by the farmer and Beaver Engineering Sdn Bhd, Brunei.

A targeted revolution was within 10-30RPM. So, with a simple calculation, a diameter of about 2900 mm was computed for the required revolution.

From collected data:

Pulley diameter, (D_1) = 70mm = (D_2) = (D_3), Pulley revolution (N_3) = 2900RPM, Diameter of the pulley (D_4) = 440mm. It was calculated N_4 = 461rpm

The pulleys were connected using a V-belt, and the belt selection was done based on a standard procedure as mentioned in machinery handbook [5]. The type of pulley-belt arrangement is called a compound belt drive [5] where the power transmission is transmitted from one pulley to another. The first step speed reduction was setup as shown in Figure 1 followed by a second step speed reduction using a gearbox as shown in Figures 2 & 3.

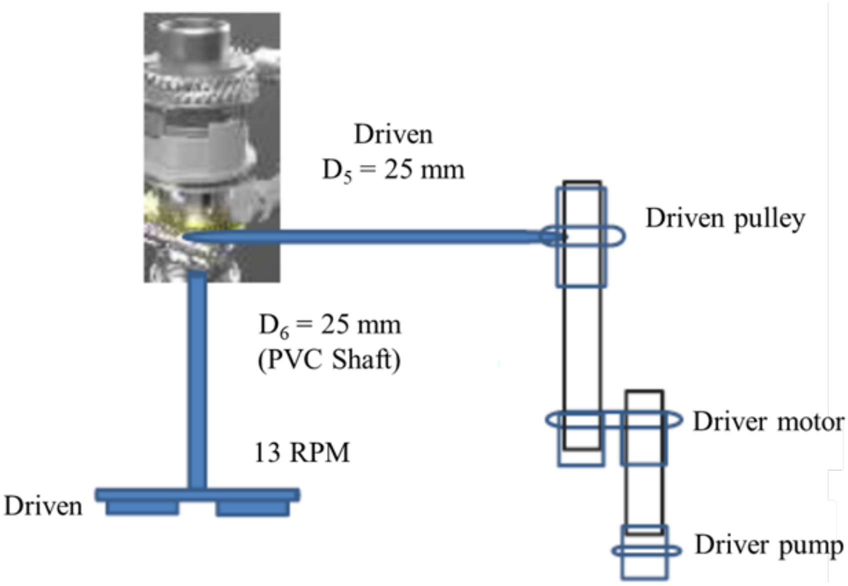

Figure 3: second step speed reduction using gearbox.

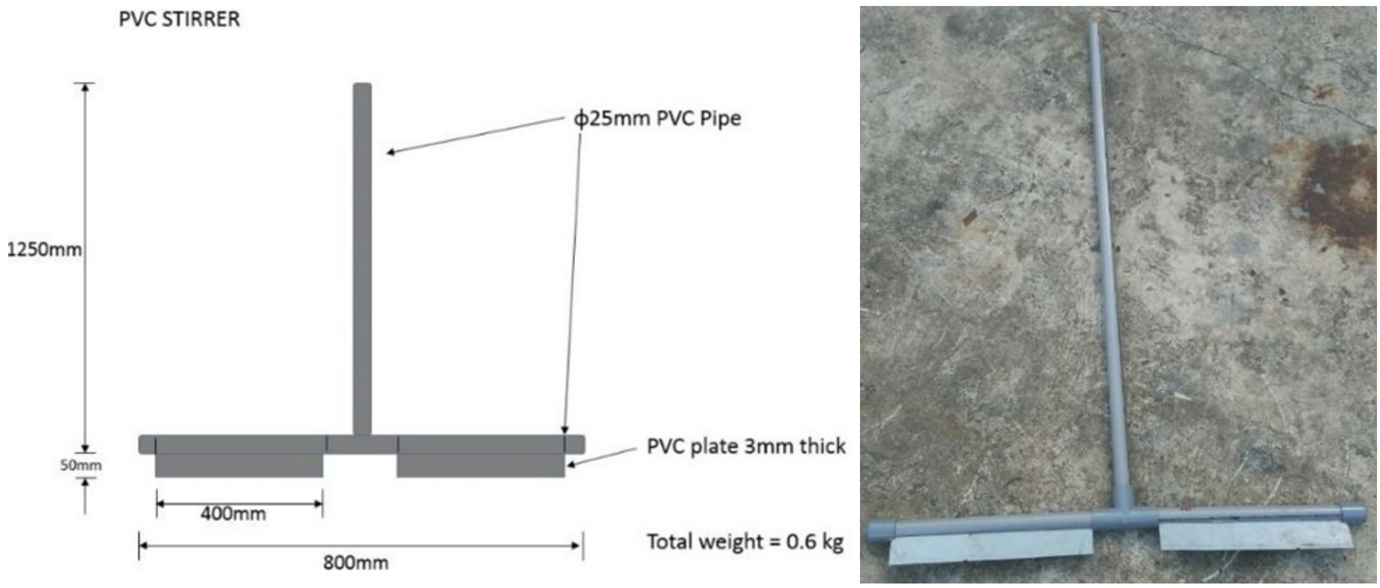

Figure 4: PVC stirrer.

The stirrer is made of a light PVC stirrer which weighted around 0.6kg. It has a diameter of 0.8m and 1.25m shaft length so that it can easily rotate inside the water tank. A rectangular shaped impeller was attached at the end of the shaft and slightly slanted at 15° which acts as a stirrer (Figure 4). The PVC stirrer design was based and referred from the design stress rating for PVC pipe [6].

The framework support material was made of mild steel angle iron welded together to give a proper and stable seat for the pump and motor unit. It was bolted to the concrete block for a more stable foundation. The overall thickness is 5mm, and the dimensions are show in Figure 5. The structure bending stresses was referred accordingly to a standard design capacity table [7]. The main performance tests were to measure the rotational speed of the stirrer in one minute (RPM) and the power it's consume from the motor as well as the volume flow rate of the pumps.

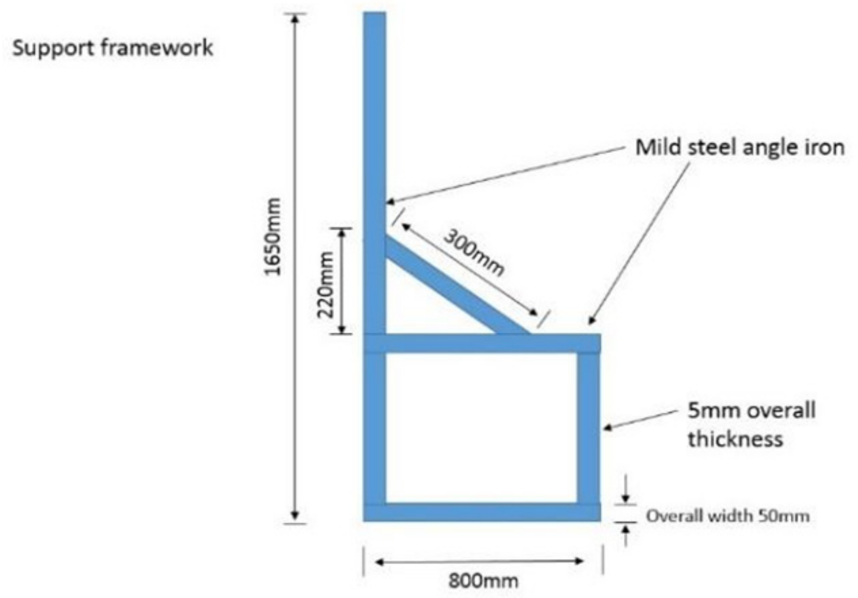

Figure 5: Support framework.

All the other necessary parameters such as current, voltage, and pulley speed were recorded and tabulated in tables 1 and 2. On measuring the volume flowrate, a bucket of 18 liter was filled and time required to filled-up was recorded. Three attempts were made, and an average was computed.

Table 1: Power consumption of the stirrer mechanism.

Stirrer System	Description	Results Without Load	Results with Load	% Difference
Motor	Ampere (Amps)	4.78	5.28	9.47%
	Voltage (volts)	246.9	246.9	No change
	Output Power (KW)	2.2	2.2	No change
	Speed (Rpm)	2964	2960	0.13%
	Speed of big pulley (RPM)	424	416	1.89%
Stirrer Power utilize by stirrer	Speed (RPM)	15	13	13.33%
	Watt	3.7 Watt	3.2 Watt	13.50%

Table 2: Volume flowrate of the pump with stirrer and without stirrer mechanism.

Test No.	Complete System	Pump Only (Without Stirrer)
1	1.619L /s	1.754L/s
2	1.796L/s	1.726L/s
3	1.442L/s	1.673L/s
Average	1.678L/s	1.718L/s
Difference	144 L/hour (2.4L/min)	
% Difference	2.33%	

The following equations were used to calculate the power and torque:

$$\text{Power} = 2\pi T N \quad (1)$$

$$\text{Torque} = F R \quad (2)$$

Where, T = Torque, N = Revolution speed, RPM, F = Force, Newton, and R = Radius of the stirrer, m.

Sample calculation

Power utilized by the stirrer mechanism itself was calculated from equation (1). Weight of the stirrer was 0.6kg.

Power = 2 π TN Where, Torque = $F R$ (1kg of mass = 9.81 Newton)

Force = 0.6kg × 9.81N/kg = 5.88N, Radius of stirrer = 0.4 m

Hence, Torque, = 5.88N × 0.4m Or, Torque = 2.352 N.m

So, power = $2\pi TN$ = 2 π × 2.352 N.m × (13/60) (rad/s) Or, Power = 3.2Watt at rotational speed 13rpm.

Therefore, the power utilize was 3.2 Watt only from the input power of 2200 Watt without considering any loss.

Results and Discussion

The system was operating well without any problem. Further research needs to be done to analyze the mixing index of fertilizer and water at different speeds of the stirrer. It is recommended that such test needs to be carried out to determine its solubility of the mixing by taking a jar sampling and let it settle for a set duration say about 1 hour. If there are no sediment at the bottom of the jar, the mixture is considered well mixed and diluted. This also depends on the type of fertilizer and the data should be referred to the product specification. The safety factor of the PVC stirrer, belt design and support framework were not determined, and these should be computed and referred to a standard design handbook. This could also help to decide either these items are under or over design. The 15° degrees slant of the stirrer plate was a trial version, and it was not thoroughly analyzed using a related software. The mixing tank is acting as a master storage rather than a distribution tank. The mixing can be done and distributed to other tanks before it is injected to the crops. The length of the shaft could be shortened to increase more power to be transmitted. The system has its own limitation and needs further improvement in the future. The machine was not fully tested with fertilizer and fed onto the crops because of liability issue which might ruin the farm crops.

Conclusion

An automatic stirring mechanism was successfully designed, fabricated, installed, and tested. The speed reduction was achieved by using two steps reductions power i.e., by using the belt-pulley mechanism and the speed reduction gearbox. The motor speed was successfully reduced from 2900rpm to the speed of the lightweight PVC stirrer at 13rpm. The slow mixing tank also helped the farmer to mix the fertilizer easily compared to previously manual and labor-intensive mixing. This project also demonstrated that the same power source could be utilized for stirring mechanism. The mechanism only took about 3.2 watt of power from the primary source. Therefore, there were no wastage of energy and the cost of employing a labor can be saved. Moreover, there was no major effect on the volume flowrate of the pump with the installation of the stirrer with the only difference of 144 liter per hour. Although the tank was purposely for fertigation, but it could be used for other purpose such as light soil agitator to mix compose. While mixing avoid sedimentation of fertilizer, further studies need to be done on the dripper of the fertilizer and the flow rate that it need for efficient feeding. Simulation of the mixing using a suitable software like ANSYS FLUENT could be implemented. Meanwhile the viscosity of the liquid fertilizer can be studied and analyzed. Proper mixing was not the only solution to clogging problem, other factors also contributed to these issues such as the quality of water and incompatibility of the fertilizer.

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