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DESIGN AND FABRICATION OF A TREATMENT SYSTEM FOR REDUCING SALINITY AND HEAVY METALS IN IRRIGATION WATER

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ABSTRACT

This paper investigated the use of hydraulic ram pump on the high pressure feed side of a reverse osmosis to reduce salinity, and heavy metals such as lead, chromium and copper in irrigation water. The influent and effluent water qualities were analysed using standard methods to ascertain the performance of the treatment system. The results showed that the electrical conductivity of the saline water was reduced from 2,310 µs/cm to 178 µs/cm. Lead, chromium and copper concentrations were reduced from 0.254mg/l, 0.020mg/l and 0.380 mg/l to 0.005 mg/l, 0.01 mg/l and 0.08 mg/l, respectively. The concentrations of the effluent parameters were within the Food and Agricultural Organization (FAO) of the United Nations standards for irrigation water. This implies that the design and fabrication of the system should be encouraged for the application of good quality water to farmlands. This system is recommended for the nations' rural areas irrigation farming to ensure national sustainable development.

Key words: Hydraulic ram pumps, reverse osmosis, irrigation, salinity, heavy metals, irrigation farming

INTRODUCTION

Irrigation is the process of supplying a controlled amount of water to plants at regular intervals to boost agricultural produce (Wikipedia, 2017). Irrigation can contribute to soil salinity if the applied water is saline or there is lack of drainage systems in irrigated lands (FAO, 1985). A saline soil is defined as one in which the electrical conductivity of the saturation extract (ECe) in the root zone exceeds $4dSm^{-1}$ (approximately 40 mMNacl) at $25^{o}C$ and has an exchangeable sodium of 15% (Shrivastava and Kumar, 2014). Crops grown on saline soils suffer on an account of high osmotic stress, toxicities, nutritional disorder, poor soil physical conditions and reduced crop productivity. According to Shrivastava and Kumar (2014), the salinized areas of the world are increasing at a rate of 10% annually for reasons such as low precipitation, high evaporation, weathering of native rocks and irrigation with saline water, which leads to secondary salinization. The area under salinity would continue to increase yearly due to the introduction of irrigation practice in new areas and studies have shown that more than 50% of the global arable land would be salinized by the year 2050 (Patel et al., 2011; Jamil et al., 2011).

Apart from salinity, irrigation water can also introduce heavy metals in the root zones, in excess of plant requirement. Heavy metals in high concentrations inhibit cytoplasmic enzymes and cause damage to cell structures due to oxidative stress (Asati et al., 2010; Assche and Clijsters, 1990; Jadia and Fulekar, 1999). Also, high concentrations of metals can lead to a reduction in the number of beneficial soil micro-organisms causing a decrease in organic matter decomposition and consequently less soil fertility.

As a result of the adverse effects of salinity and heavy metals on plant growth, it is important to treat irrigation water containing these substances before use, especially if there are no alternative water sources. A viable means of removing salinity and heavy metals from water is the use of reverse osmosis, which selectively allows the passage of water molecules while partially or completely retaining other molecules or ions (Michael, 2013). However, reverse osmosis requires a high pressure pump, on the high pressure feed side, which increases the running and maintenance cost of the system. To make the system affordable and acceptable to peasant farmers, it is important to operate it with a type of pump, such as a hydraulic ram pump, that is simple and requires no fuel to operate. Hydraulic ram pump is a cyclic water pump powered by water surge. The main components are drive pipe, delivery pipe, air vessel, waste valve, intake tank and delivery tank as shown in Figure 1.

The aim of this study is to design and fabricate a treatment system for reducing salinity and heavy metals in irrigation water using reverse osmosis and a hydraulic ram pump to boost farm produce and enhance the nations' sustainable development.

MATERIALS AND METHODS

Materials

The following materials were used in carrying out the fabrication of the system:

¾"pvc pipe, 0.6-metre-high: This was used as the drive pipe to the hydraulic ram pump.

1/2"pvc pipe, 0.34-metre-long: This was the delivery or driven pipe which channels the water at a greater pressure than the water entering the drive pipe.

¾" tees: These direct the flow in two directions

¾" elbows: These were used to connect two pipes at a 90 degree angle.

3" pipe: This pipe was used as a pressure vessel. The pressure vessel compresses and cushions the pressure pulse from the ram cycle, allowing a steadier flow through the delivery pipe with less friction loss.

Partially pumped bicycle tube: This helped to prevent air loss in the pressure vessel. The air stored in the pressure vessel was either slowly absorbed by the turbulence of the water entering through the delivery valve, or lost into the delivery pipe.

Impulse valve**:** A swing check valve was used in this case as the impulse valve. It built up the powerful hammer pulse needed to drive water to high heads.

Delivery valve**:** A simple swing check non return valve was used as the impulse valve.

The delivery valve had an opening to allow the pump water to enter the air chamber with little obstruction to flow.

Vontron low pressure RO membrane: This is a Vontron manufactured 75gallon per day discharge reverse osmosis membrane which operates at pressures as low as 0.2 bar.

RO membrane feeder tubes: these connect from the delivery pipe to the reverse osmosis membrane.

Method

Sample Collection

\Water sample were collected from sources noted for high salinity and heavy metal concentrations in Obi Local Government Area, Benue State, and Anka community, Zamfara State, respectively(MSF, 2012). At the sampling points, there are farming activities that might rely on the use of the water for irrigation. The sample locations were shown in Figures 2 and 3.

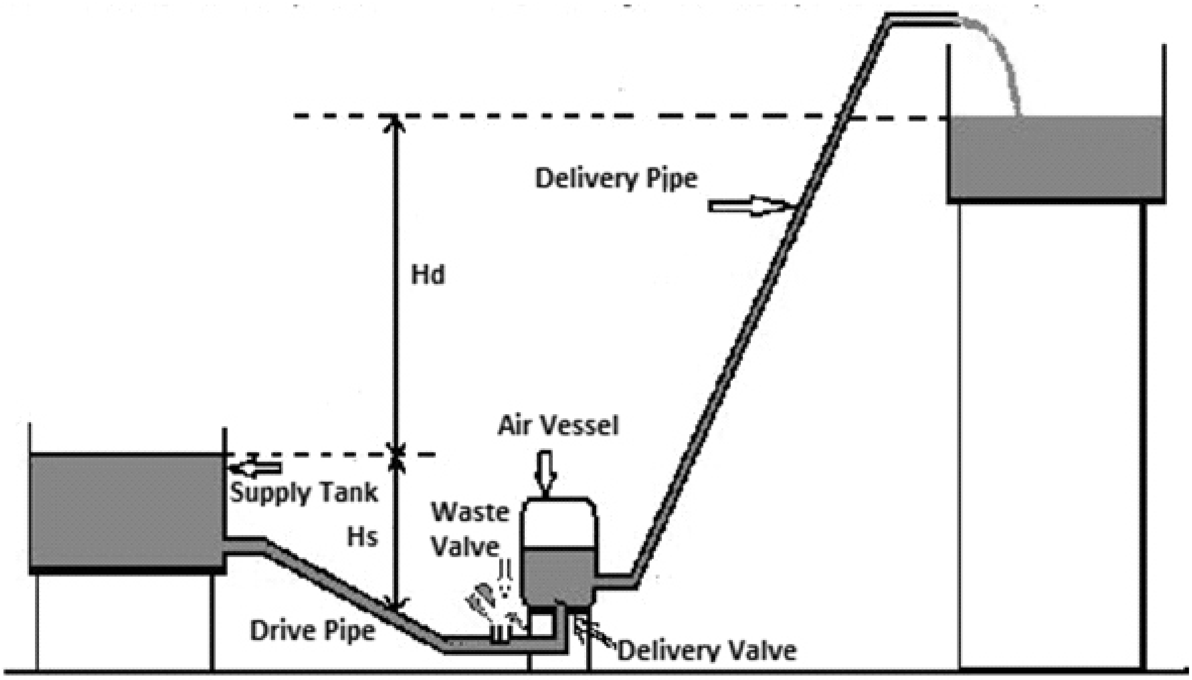

Figure 1: Hydraulic Ram Pump Assembly (Source: Maw and Htet, 2014; with modification)

Figure 2: Sampling point, Obi community, Benue State, (Source: Google Earth)

Figure 2: Sampling point, Anka community, Zamfara State, (Source: Google Earth).

Design of Hydraulic Ram Pump

The design and fabrication of the essential components of an hydraulic ram pump were highlighted as follows:

Drive pipe length (L): The drive pipe length (L) was made longer than the delivery pipe, that is, about twice and assumed to be 0.6m.

Delivery pipe length: The delivery pipe length was made shorter, about half of the drive pipe, to reduce head loss due to friction in a lengthy pipe and to be able to supply high pressure on the feed side of the reverse osmosis The length was assumed to be 0.34m. Also, the pipe diameter was designed such that itis about half of the drive pipe (Maw and Htet, 2014).

Waste valve: The flow area through the waste valve was designed such that it equalled the cross sectional area of the drive pipe to avoid 'choking' of the flow (Balgude et. al., 2015).

Delivery valve: The air vessel with the delivery valve opening was selected such that the cross-sectional area through the valve approximately equalled the drive pipe diameter.

Source flow rate: The source flow rate was assumed to be 3.2 litres/min. This was regulated with a valve.

Lift Required: The lift required above the pump was 1.2m. However, the delivery pipe was made shorter than 1.2m as explained before so that high pressure could be available on the feed side of the reverse osmosis.

Actual supply from ram: The actual supply from the ram was determined by actually measuring the volume of water delivered per min.

Other parameters considered in designing the hydraulic ram pump were:

From the stated statistics, the supply by the ram was calculated using the following Equation 1.

$$D=(S \times F \times E)/L \quad (1)$$

where:
D = Amount delivered in litres per minute.
S = Quantity of water supplied in litres per minute.
F = The fall or height of the source above the ram in meters.
E = The efficiency of the ram was assumed to be 0.33 (Watt, 1975)
L = The lift height of the point of use above the ram in meters
For the flow through the system, the following quantities were calculated to evaluate the hydraulics and efficiency of the pump:

The velocity of fluid flow in the driven pipe, given by

$$V_d = \frac{Q}{A_d} \quad (2)$$

where, V_d = velocity of fluid flow and A_d = area of pipe.

The Reynolds number given by

$$R_e = \frac{V_d}{V} \quad (3)$$

where, V = velocity of fluid flow, d = pipe diameter and = kinematic viscosity of water at 20^0C.

The frictional factor for circular pipes, given by

$$f = \frac{64}{Re} \quad (4)$$

where, f = frictional factor of the pipe and Re is Reynolds number.

The DarcyWeisbachhead loss formula in pipes given by

$$\text{Head loss} = f\ \frac{l}{d}\left(\frac{V^2}{2g}\right) \quad (5)$$

where, g = acceleration due to gravity, *l*= length of the pipe, V= fluid velocity and d = pipe diameter.

Other losses of head, as in pipe fittings were calculated using

$$H_L = K_T\,\frac{V^2}{2g} \quad (6)$$

where H_L is other losses, K_T is pipe coefficient, other parameters are as defined before

For the efficiency of the Ram pump, Rankine method given by Equation (7) is used.

$$E = \frac{Q_p^{xh}}{Q_s^{xHs}} \quad (7)$$

where "E" is the efficiency of the hydram, Q_p is the delivery pumped flow (l/min), Q_s is the supply flow (l/min), h is the delivery head and H_s is the supply head above the waste valve opening.

The power of the pump can be calculated using this expression:

$$P = pgQh \quad (8)$$

where density (ñ) = 1000 kg/m^3, acceleration due to gravity (g) = 9.81m/s^2, Q = actual discharge (m^3/s), h = delivery head (m)

Reverse Osmosis Membrane Selection

The reverse osmosis membrane for the treatment was purchased. It's model is a Vontron ULP11812-75, designed for water filtration and capable of working under extremely low pressure (as low as 0.2bar). It has 75 gallons per day as its permeated flow and a maximum operating temperature of 45°C.

Experimental Set-up

The experimental setup involves the hydraulic ram pump in connection with the RO membrane As presented in Figures 4 and 5.

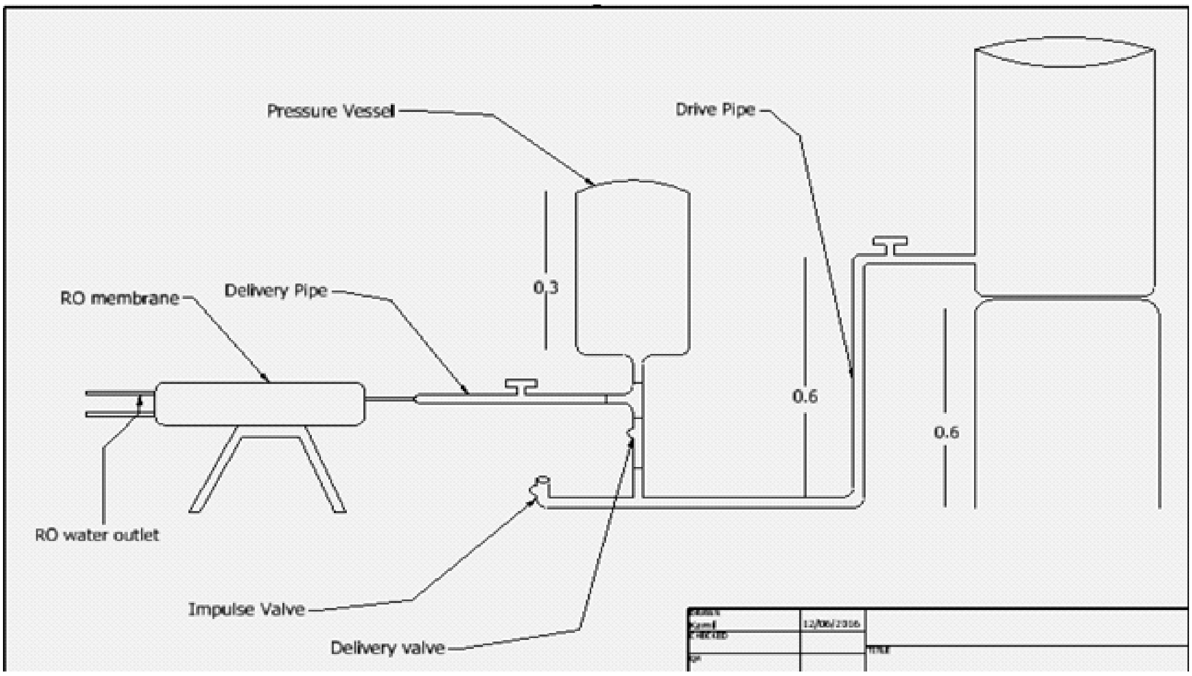

Figure 4: Hydraulic Ram Pump-Reverse Osmosis Schematics Set-up

Figure 5: Hydraulic Ram Pump- Reverse Osmosis Experimental Set Up

Laboratory Analyses

Influent and Effluents were collected from the treatment set up for laboratory analyses. The effluent results were compared with irrigation water quality standards by Food and Agriculture Organisation (FAO)of the United Nations to see if the system is efficient in treating the water. The parameters considered were Electrical Conductivity for salinity, and Lead, Cadbium and Copper as heavy metals. Salinity was determined by using Electrical Conductivity Method (Reference Number: 2520B) and the heavy metals were analysed by using Flame Atomic Absorption Spectrometry (Reference Numbers: 3111B and 3111C) as contained in Standard Methods for Water and Wastewater (APHA, 1999).

RESULTS AND DISCUSSION

The results of the treatment system set up and the laboratory analyses of the water quality parameters evaluated are presented as follows:

Hydraulic Ram Pump

The results of the hydraulic parameters of the pump are presented in Table 1 and discussed as follow:

Drive Pipe Length: The drive pipe length was selected such the pipe's length and diameter are about half those of the delivery pipe. Hence, a drive pipe of length 0.6m and diameter 3/4inch (0.01905m) was selected.

Delivery Pipe Length: To reduce head loss due to friction, a delivery pipe of length 0.34m, about half the drive pipe, was selected. Also, it was ensured that the delivery pipe diameter was ½ inch (0.0127m), that is, about half the drive pipe size (Maw and Htet, 2014).

Waste Valve and Delivery Valve openings were selected such that their cross sectional areas approximately equal the drive pipe diameter. The source flow rate was assumed to be 3.2 litres/min and the flow was regulated with a valve.

The pressure at the delivery pipe was measured using a pressure guage and was obtained as 0.12bar (12.7 KN/m^2).The Calculated discharge using Equation (1) was obtained to be $8.799\times10^{-6}m^3/s$ (0.53liters/min), where the efficiency was assumed to be 33%.The Actual discharge from the delivery pipe was measured by noting the volume of water obtained in a minute. This was obtained to be 0.9lt/min ($1.5\times10^{-5}m^3/s$). The difference in the calculated discharge and actual discharge showed that the pump performed at higher efficiency than the assumed 33% obtained from the literature.The total head loss in the system was a summation of the major head loss using equations (2) to (5) and the minor head losses obtained was 1.21×10^{-1}m using equation (6). This head loss was minimal also reflected the calculated discharge of 0.53liters/min from the pump, using 33% efficiency, was underestimated.

As a check, the pump efficiency was calculated using Equation (7) and the value obtained was used to compute the discharge at the efficiency and then compared with the actual discharge of 0.9 liters/min. Hence, efficiency of the pump was calculated as 56.25% and the calculated discharged at this efficiency was computed as 0.8904liters/min which is approximately equal to the actual measured discharge of 0.9 liters/sec.

The power of the pump was obtained as 0.176KW using equation (8).This power is minimal;an important feature of hydraulic ram pumps, and in agreement to similar study by Sampath*et. al.* (2015) in which power of 0.73KW was estimated for an hydraulic ram pump with a supply head of 1.5m and efficiency of 59.5%.

Table1:Hydraulic parameters of pump

S/N	Parameters	Values
1	Drive pipe length	0.6m
2	Drive pipe diameter	0.0019m
3	Delivery pipe length	0.34 m
4	Delivery pipe diameter	0.0127m
5	Pressure at the delivery pipe	12.7 KN/m^2 (0.12bar)
6	Supply from source	5.3 $10^{-5}m^3/s$ (3.2lt/min)
7	Calculated Discharge from delivery pipe	8.8 $10^{-6}m^3/s$ (0.53lt/min)
8	Actual Discharge from the delivery pipe	1.5 $10^{-5}m^3/s$(0.9lt/min)
9	Efficiency of the pump	56.25%
10	Power of the pump	0.176KW
11	Total head loss in the system	1.21 10^{-1}m

Laboratory Analyses

Salinity

The results of Electrical Conductivity are presented in Table 2. The Electrical Conductivity of the raw sample was reduced from of 2310µs/cm to 627µs/cm the first day, after passing through the reverse osmosis membrane, indicating a 72.85% reduction in electrical conductivity. By the second day, electrical conductivity obtained was 207µs/cm, indicating a 67% reduction. The EC concentration reduced progressively until the fifth and the sixth day when the observed EC was 178µs/cm, with no noticeable reduction. The tests showed reduction in percentage of salts by the membrane as the salt concentrations in the sample reduced progressively and then became relatively constant. From the first day of analysis, the observed electrical conductivity of 627µs/cm is within the Food and Agricultural Organization (FAO) standard for irrigation.

Table 2: Results of Electrical Conductivity

Parameter	Raw	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	FAO Standard
Electrical Conductivity (EC) (s/cm) at27C	2310	627	207	186	181	178	178	800

Heavy Metals

The results of heavy metal analyses are presented in Table 3.

Lead

The raw water sample lead concentration of 0.234mg/l was reduced to 0.032mg/l after passing through the reverse osmosis membrane on the first day, indicating a 86.15% decrease in lead concentration. On passing through the membrane the second day, the lead concentration was reduced to 0.006mg/l, reflecting an 81.25% rejection. The third day, lead concentration was reduced to 0.005mg/l, indicating a 0.20% rejection and the fourth day and subsequently, lead concentration was still 0.005mg/l each day, indicating no lead rejection. From the first passage through the membrane, the lead concentration of 0.032mg/l is within the FAO standard for irrigation.

Cadmium

The raw water sample had an initial cadmium concentration of 0.020mg/l which was reduced to 0.010mg/l after passing through the reverse osmosis membrane the first day, indicating a 50% decrease in cadmium concentration. On passing through the membrane on the second day, cadmium concentration was still 0.010mg/l indicating no cadmium rejection. From the first passage through the membrane, the cadmium concentration of 0.010mg/l is within the FAO standard for irrigation.

Copper
The concentration of copper in the raw water sample was reduced from 0.380mg/l to 0.100mg/l after passing through the reverse osmosis membrane the first day, reflecting a 67% decrease in copper concentration. The following day, copper concentration was 0.08mg/l indicating a 20% decrease in copper concentration and the third, the concentration remained 0.08mg/l indicating no lead rejection. Subsequently, the concentration remained 0.08mg/l. From the first passing through the membrane, the copper concentration of 0.010mg/l is within the FAO standard for irrigation.

Table 3:Results of Heavy Metals

Parameters	Raw	Day 1	Day 2	Day3	Day4	Day 5	Day6	FAO Standard
Lead (mg/l)	0.254	0.032	0.006	0.005	0.005	0.005	0.005	5.000
Cadmium (mg/l)	0.020	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Copper (mg/l)	0.380	0.100	0.080	0.080	0.080	0.080	0.080	0.200

CONCLUSION AND RECOMMENDATIONS

Conclusion

This paper investigated the use of hydraulic ram pump and reverse osmosis system as a treatment unit for irrigation water containing high concentrations of saline and heavy metals. The results indicated that the electrical conductivity of the saline water was reduced from 2,310 µs/cm to 178 µs/cm. Also, lead, chromium and copper concentrations were reduced from 0.254mg/l, 0.020mg/l and 0.380 mg/l to 0.005 mg/l, 0.01 mg/l and 0.08 mg/l, respectively. The concentrations of the effluent parameters were within the FAO standards for irrigation water. This implies that the design and fabrication of the system should be encouraged for the application of good quality water to farmlands to increase production and enhance national sustainable development.

Recommendation
Although, the hydraulic ram pump and reverse osmosis system delivers small amount of water, it is recommended that possibility of installing many of such systems in parallel to supply large amount of good quality water to farmlands should be examined to boost the quantity of acceptable water to farmlands .

Study Limitation: The limitation of the study is the lack of availability of materials. As a result, locally available materials were used for the investigation.

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